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EARTHQUAKE HAZARDS REDUCTION ACT AUTHORIZATION

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HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

NINETY-SEVENTH CONGRESS

FIRST SESSION

ON

EARTHQUAKE HAZARDS REDUCTION ACT AUTHORIZATION

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EARTHQUAKE HAZARDS REDUCTION ACT AUTHORIZATION

MONDAY, APRIL 6, 1981

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY AND SPACE,
Washington, D.C.

The subcommittee met at 1:05 p.m. in room 1318 of the Dirksen Senate Office Building; Hon. Harrison H. Schmitt (chairman of the subcommittee) presiding.

OPENING STATEMENT BY SENATOR SCHMITT

Senator SCHMITT. The subcommittee will come to order.

I want to welcome all of you this afternoon for the reauthorization hearings for the earthquake hazard reduction program, enacted by the Congress in 1977 as Public Law 95-124. I think everybody is aware, either through their own experience or through the newspapers or books, that earthquakes can devastate cities. They have throughout recorded history; but as the population of various areas of the world and this country grow, the potential loss of life and property escalates with alarming rapidity.

These earthquakes occur with irregular frequencies, at least so far as we know; but still, in a sense, on a very regular basis. And the question is, is that basis predictable?

Recent examples of earthquakes are those that devastated Managua, Nicaragua in December 1972; the Guatemalan earthquake of 1976; and, of course, some recent activity even in this country. One of the ones that probably should figure most prominently in planning for this country's activities was the San Fernando Valley earthquake in 1971.

The Nicaraguan event resulted in 5,000 to 10,000 deaths and a property loss equivalent to the annual gross national product of that country. The earthquake in Guatemala caused 20,000 deaths and left a million people homeless, one-sixth of the entire population. The earthquake which struck northern Italy on May 6, 1976 caused approximately 1,000 deaths and destroyed thousands of homes.

I think it is safe to say that properly placed along the San Andreas fault, there are a number of localities where we could anticipate upwards of a million casualties, should the right magnitude earthquake occur in the right place. There are probably other areas in this country where the history of earthquake activity would suggest that maybe comparable, but certainly sizable earthquake losses could result at almost any time, although that time is statistically infrequent.

The earthquake hazard reduction program recognizes the seriousness of this threat, although not to the degree that this Senator had hoped that it would. And it also recognized that reduction of loss, destruction, and disruption from earthquakes would depend upon the actions of individuals and organizations in the private sector and the governmental units at Federal, State, and local levels.

Our capability to transfer knowledge and information to these sectors did appear, at that time, to be insufficient, and there is evidence that it still is. The purpose of the act was to reduce the risks to life and property from future earthquakes in the United States with the establishment and maintenance of an effective earthquake hazards reduction program.

The purpose of our hearing this afternoon is to discuss how far we have come toward achieving this goal. We would want to discuss the organizational structure and effectiveness of the program with the Federal Emergency Management Agency, FEMA, as the lead Agency.

We would also like to highlight preparedness aspects of the program, and I personally will have some questions, as I have in the past, on the nature of efforts toward prediction of earthquakes.

The witnesses we have here today represent the Federal Emergency Management Agency, the National Science Foundation, and the U.S. Geological Survey; and we had hoped to have Mr. Carl Ledbetter, who is a project director of the southern California earthquake preparedness project. Unfortunately, he was not prepared for airline schedules, and is stuck in St. Louis. We will have his testimony, I am sure, for our record, and it will be studied by the subcommittee.

I would ask each witness to limit his opening remarks to approximately 5 minutes so we could proceed into the questions and a general discussion of the issues.

Our first witness is Mr. Robert Crawford, Acting Associate Director for Mitigation and Research of the Federal Emergency Management Agency. I believe you are accompanied by Charles Thiel.

Let me say also that it is going to be very difficult for the subcommittee to provide a definitive reorientation, if that is necessary, of the earthquake program this year. The authorization cycle is such that we must proceed expeditiously, but we do not have a science and technology infrastructure fully in place within the new administration commensurate with our need to communicate with that administration on what might be and should be done in this area, or many other areas of science and technology policy.

So I suspect the inclination of the subcommittee will be for a 1-year reauthorization, so during that year we can work directly and substantively with the administration to see if anything should be done, in addition to what already is available in the statute.

Mr. Crawford, would you proceed?

STATEMENT OF ROBERT CRAWFORD, ACTING ASSOCIATE DIRECTOR, MITIGATION AND RESEARCH, FEDERAL EMERGENCY MANAGEMENT AGENCY, ACCOMPANIED BY CHARLES C. THIEL, ASSISTANT ASSOCIATE DIRECTOR

Mr. CRAWFORD. Thank you, Mr. Chairman. I have submitted a detailed statement to the committee, and in accordance with your suggestion, I would like to restrict my remarks at this time to summarizing and highlighting significant points about FEMA's earthquake activities.

As you indicated, sir, I am accompanied here today by Dr. Charles C. Thiel, Assistant Associate Director for Mitigation and Research at FEMA. Dr. Thiel is responsible for FEMA's activities in the earthquake hazards reduction program and has been involved in the evolution of this activity for over 10 years. As a result, he is one of the most knowledgeable individuals in the country about plans and activities in this area, and I am pleased to have him here with me today.

Following my statement we would be pleased to respond to questions.

I would like to begin by pointing out that earthquakes pose a truly national risk. Great earthquakes have occurred during the last 300 years in Massachusetts, New York, South Carolina, Missouri, Washington, Alaska, Nevada, and of course, California. These events have affected not only those states, but in some cases very large surrounding regions.

All or portions of 39 States—a map showing this is included within my full statement—and all of our territories are at major or moderate earthquake risk, with about 35 percent of our population residing in these areas. Among all the geophysical hazards, none poses a threat to life and property similar to that posed by a single catastrophic earthquake. One such event which could occur in California, could, for example, cause over $50 billion worth of property damage and a loss of life exceeding 20,000 with, of course, tens of thousands of additional persons injured.

We have been most fortunate in the last 100 years in that our losses from earthquakes have been limited. Our understanding of the historical records and of current geophysical processes indicates that such continuing good fortune is highly unlikely.

My testimony examines the overall objectives of the national program, discusses specific FEMA accomplishments and initiatives, and describes the specific issue which we believe should be considered in the reauthorization of the national earthquake hazard reduction program.

As you indicated, sir, in your opening remarks, the purpose of the national program is to reduce the risk to life and property from future earthquakes in the United States by the establishment of an effective earthquake hazards reduction program. In our judgment, this purpose is still sound and comprehensive. The act has set forth a broad set of objectives which are achievable and appropriate.

FEMA's role is comprehensive, involving not only the coordination of earthquake hazards reduction policies and the activities of Federal agencies and departments, but also there are other specific activities which have been assigned. These include the lead role in the planning and coordination of the national program, the development and encouragement of the application of earthquake mitigation by all levels of government, and the provision of emergency and recovery assistance when State and local resources are insufficient to respond.

Other Federal agencies are assigned responsibilities for maintaining a comprehensive program of research and development in the area of earthquake prediction and hazard mitigation, and incorporating earthquake mitigation and preparedness into mission programs, policies, and activities.

Now, I would like to briefly address selective aspects of the activities which have been going on in this area. First, the National Security Council study. As a result of former President Carter's concern about the impact of a catastrophic earthquake in California, the ad hoc committee of the National Security Council was formed to conduct a Government study of the consequences of and preparation for such an event. In addition to FEMA, the study included contributions from several other agencies and White House offices, representatives of the State of California's agencies, California local governments, and consultants from the private sector.

The assessment concluded that the Nation is essentially unprepared for the catastrophic earthquake in California that can be expected to occur in the coming decades. While response plans and preparedness measures may be adequate for the occurrence of moderate earthquakes, substantial steps need to be taken to cope adequately with the consequences of the occurrence of a catastrophic quake striking in a large, urbanized area in California. Based upon this assessment, FEMA was charged by President Carter to provide aggressive leadership throughout the Federal Government, and to serve as a focus for cooperation with California in preparing for the predicted or unpredicted catastrophic earthquakes.

This activity meshes with the Southern California earthquake preparedness program. In this program, officials from the California Legislature, the California executive departments, local governments, representatives of the private sector in southern California and FEMA were developing an innovative, federated effort to enhance the public safety through improving substantive preparedness planning and programs capable of responding to the occurrence and prediction of a catastrophic earthquake, even before the NSC assessment got underway.

Through their combined efforts, a cooperative program has been developed in which State and local government, the Federal Government, and the private sector are participating. The program is being managed by the California Safety Commission, under the guidance of a policy committee with representatives principally from the local community. We are very pleased to be involved in this innovative approach to emergency planning. The essential premise of the undertaking is that no single element of government has sufficient resources or capabilities to respond to the expected needs in the time of an earthquake disaster.

Among the other important activities in the earthquake hazards reduction program are those being conducted by two key bodies which address the issue of improved building practices. The impact of both of these groups is national in scope, and they are making significant contributions in their areas of concern. The first of these activities is the Interagency Committee on Seismic Safety and Construction, which has continued to act as the focus for the development of improved building practices and the underlying processes for their application. The committee utilizes the services of more than 150 individuals representing 17 Federal agencies, and has been quite active during the past year.

The second group is the Building Seismic and Safety Council. This Council was conceived in 1979 as an entirely new kind of instrument for dealing with the complex technical, social, economic, and public and private jurisdictional issues involved in developing and promulgating improved seismic design provisions on a national scope. In large measure, it was set up in response to the need for a unique combination of individuals and institutions to address the extremely complex regulatory environment which typifies the building industry. During the past year, the Council has completed an extensive review of the Applied Technology Council document tentative provisions for the development of seismic regulations for buildings.

Before concluding my summary of the earthquake hazards mitigation program in FEMA, I would like to spend just a moment in outlining an issue which we deem to be of particular importance in this area. The initiatives of the past 10 years following the San Fernando earthquake of 1971, and particularly the research efforts of the past 5 years, have built a substantial base of knowledge of earthquake hazard mitigation. This foundation of knowledge has been developed by taking advantage of the individual initiatives of separate researchers working, by and large, in the areas which have the most scientific promise. Generally, this mode of scientific development has been, in our judgment, the appropriate research management strategy. However, there is sufficient knowledge and experience now to initiate a larger proportion of project-oriented activities designed to develop, test, and demonstrate the efficacy and cost-effectiveness of earthquake hazards mitigation strategies. We believe that now is the time to augment the existing program by the initiation of a project orientation, while at the same time maintaining the disciplinary, individual investigator, research program.

Mr. Chairman, we feel that FEMA's activity in the area of earthquake hazard reduction offers significant potential for improving the ability of the United States to mitigate the consequences of destructive earthquakes. With regard to FEMA's designation as the lead agency for the program, I think it can be safely stated that FEMA has carried out that role in a workmanlike manner since its establishment, even in the face of heavy competition for the resources available to the agency. Close relationships have been maintained, often on a day-to-day basis, with the other key institutions involved in the program, and significant trading of knowledge and coordination of activities has resulted. We are committed in FEMA to an active, aggressive program in this area, and will continue to emphasize our partnership approach as we work with other Federal agencies, State and local governments, and the private sector in strengthening our country's earthquake mitigation and preparedness posture.

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Dr. Thiel and I would now be pleased to respond to any questions you may have, sir.

Senator SCHMITT. Thank you, Mr. Crawford.

I, of course, feel that the Federal Government has shown an abysmal lack of urgency in this matter. In fact, your statement gives the conclusion of the National Security Council study that is essentially the same as some of us were trying to get you to agree to in 1977. It doesn't make me feel any better. And I am not blaming just the previous administration. I think many administrations in recent years have been, for some reason, unwilling to face the fact of the danger that is faced, not only by cities along the San Andreas and related fault systems, but some other major urban areas in this country.

I don't know what to do about that. I don't think it's going to happen this year, either, but I see no sign that we are really focusing our national capability, even within budgetary constraints, on a problem that clearly is going to leave everybody with egg on their face when it occurs.

Let me ask you, assume that you and I got a message right now that a major earthquake occurred in southern California of proportions of the worst case scale that you could envision. Could you outline in a minute or two, what would be FEMA's response to that occurrence?

Mr. CRAWFORD. Sir, if I might, Dr. Thiel has been very close to that activity in the course of his responsibilities as head of the earthquake program. So without your objection, I would like to ask him to respond.

Senator SCHMITT. Please proceed.

Dr. THIEL. The immediate step, of course, given confirmation that the event had occurred in an urbanized area, and based on a yet-to-be-formalized agreement with the State of California, we would ask the President to declare a disaster under Public Law 93-288, which would allow the use of the President's disaster relief powers.

Senator SCHMITT. That agreement you say hasn't been formalized. Would you still go ahead and proceed on that basis? I'm talking about right now.

Dr. THIEL. Yes, sir, I would, because that has been discussed between the Governor and the previous President. I am sure that Mr. Reagan would certify that agreement. That will be formal within a matter of months, as soon as we can determine how the State of California is responding.

Second, we would notify the Federal agencies that are active in that area—the Corps of Engineers, particularly—to indicate to them that they should make their goods, resources and personnel available immediately. The same with the Department of Defense.

Our response requirements and limitations at the Federal level, it must be understood, are in support of State and local government and the public. Under the strict interpretation of existing law and procedures, we would respond to requests that were made by those elements of government, and provide supplementary assistance.

I am satisfied, and have been satisfied for a number of years, that the demands are going to saturate any capacity that the

Federal Government or the State government have to respond, so we would make available immediately, to the extent possible, all of the resources that we would have access to.

If I could make one other comment, there is a general perception that in time of disaster, there needs to be a very strong show of government, particularly centralized government. There is considerable evidence to suggest that that is not required in the immediate post-occurrence period; that individuals and institutions are very resilient, and therefore we need not come in with as high a degree of organization as we expect to need within several days.

Senator SCHMITT. What about the transfer of supplies? You mentioned that we know what is going to happen, when that earthquake is going to occur. We had very limited useful warning in the San Fernando earthquake, to which I'm afraid the city, county, and State did not sufficiently react. Nevertheless, we pretty much know what's going to happen. Many of the primary services of government will be destroyed. The communications systems go down. The transportations systems go down. Oil and gas lines are disrupted. Telephone lines disrupted. Hospitals, unfortunately, tend to be severely damaged. All the things that you can think of that you need in order to deal with a local situation are seriously disrupted, and I agree with you, people are very resilient in times of an emergency. Americans have shown that again and again, but nevertheless, over a period of many days, in a situation like we are envisioning, here, the Federal Government would seem to have a responsibility to make sure the consumables and transportation needs are provided to the area.

What is your plan to do that?

Dr. THIEL. That certainly is the case. We have executed an agreement among Federal agencies, the Department of Defense, for instance, through the Sixth Army, the Department of Transportation and Coast Guard, HHS, all of the principal Federal response agencies under the aegis of our regional director in San Francisco. This emergency plan has a group of annexes which characterize the responsibility of each agency, and they indicate how that responsibility is to be exercised. So those preliminary plans, and I call them preliminary only because I found that they're not adequate by my measures, are in place, and provide a basis for response.

Mr. Crawford indicated that we have underway a major a cooperative effort between the State and Federal Government and local government—the south California earthquake preparedness project. That project is beginning with the State, Federal, and local plans that are in place and developing from that a more coherent planning basis for response to such events. At the current time, our response will undoubtedly be characterized as inadequate, and our current plans inadequate. But I believe that we have in place a uniquely promising effort to remedy not only the deficiencies in Federal planning but the deficiencies in State and local planning as well. These plans will make clear to the public what responsibilities they are expected to bear and those that government is expected to bear.

Senator SCHMITT. Does your plan include a scheduled managerial simulation of Federal and State units that have to respond.

Dr. THIEL. Absolutely.

Senator SCHMITT. When would such a simulation be expected to occur.

Dr. THIEL. There have been several simulations within the last year of various portions of State plans, particularly, and one simulation of the Federal plan.

Senator SCHMITT. Did the President of the United States participate in the simulation?

Dr. THIEL. That's not planned at this time, but that certainly is a reasonable suggestion. How many people and what levels might participate, is always hard to predict in simulations. Generally, there will be a surrogate for a high administrative official who will take part in the test.

Senator SCHMITT. If we'd used surrogates in the simulation activities in the space program, we wouldn't be very successful. We're taking about an event of such national proportions that obviously the President is going to be called on to make certain types of very difficult decisions in the distribution of resources, decisions that will involve helping some people and not helping others. Don't you think the President ought to be involved in such a simulation?

Dr. THIEL. I do, personally, yes. I think, speaking frankly, when we look at civil defense preparedness, for instance, we ought to have a hard time, I'm told, by our plans and preparedness people, involving individuals at comparable levels for nuclear war preparedness simulations. So I think, speaking frankly, that it's unlikely, unless we can find ways to encourage them. Frankly, again, I'm not as concerned about the President as I am involving the Governor and the State of California.

Senator SCHMITT. I only used the President as an example of a high-level administrator. There are many others. The question is, to what degree is FEMA advocating the involvement of these people in mitigation exercises?

Dr. THIEL. We certainly are advocating that. Whether we will be able to accomplish it, is another matter.

Senator SCHMITT. Obviously, one of the best ways to simplify the problems of mitigation is to be able to predict and take prompt action prior to an earthquake rather than waiting until after the fact. What is your assessment from the administrative point of view now? We'll get a scientific assessment later. What is your assessment from an administrative point of view of our ability to predict, and if we could, what would you do with the information?

Dr. THIEL. That's not a particularly easy question.

Senator SCHMITT. It wasn't intended to be.

Dr. THIEL. From an administrative standpoint, I believe that we have a reasonable capability to assess the scientific credibility of the prediction itself, either through the State or the National Earthquake Prediction Evaluation Councils. There are some difficulties in aggregating that information. It's not clear for some elements in the private sector, academic institutions, and international institutions, who they would make that information available to first. Part of our southern California effort is to try to aggregate that information, develop a consistent communications program, so that the National Earthquake Prediction Evaluation

Council is informed of any prediction and prediction hypothesis that people might offer.

From the dissemination standpoint, we have in place a good communications network already. It communicates to disaster officials and responsible public officials within the local communities affected. It's redundant with the civil defense notification procedures. Again, we're working through the southern California project to refine and to make this system more germane for passing useful information to individuals. I think at this time our critical shortfall, if that's an appropriate term, in the prediction system, is the preparedness plan—to use the information that a prediction has been made, to provide adequate warning and instruction—or suggestions—to members of the public on how they can proceed to protect themselves. In a sense, we have a prediction in place in southern California now, reaffirmed by the U.S.G.S. this last summer. It's an earthquake hazard watch for southern California. It's not time specific, but it certainly is an expression of substantial risk in the area.

That coupled with other geophysical events that have been observed in California have led to a substantial increase of activity to mitigate earthquake hazards within the State. Certainly, the earthquake watch was instrumental in the city of Los Angeles hazardous building abatement program, passed just about 8 weeks ago. It requires the removal of such structures within 5 years, and within 1 year, for about 20 percent of the highest risk buildings.

Senator SCHMITT. Do you feel that if I took a poll of the residents of southern California and asked them a question of what would you do in the event of a major earthquake, that I would get a consistent response commensurate with what you would like to do?

Dr. THIEL. I think at this point I'd have to say no.

Senator SCHMITT. What then are we doing to establish in the public's mind an understanding of what is the best procedure to take, in the event of a major earthquake.

Dr. THIEL. Within the context of the southern California earthquake preparedness project, a major component, probably one-third has to do with public information and public education. In addition, the State of California, through the Governor's office, proposed on the 9th of February a $4.5 million earthquake preparedness initiative for fiscal 1982, which contained approximately $1 million for public information efforts. These are initiatives, principally at the State and local level.

Senator SCHMITT. What should the average person in Los Angeles do, in the event of a major earthquake?

Dr. THIEL. In preparing for it or responding to it?

Senator SCHMITT. Why don't you answer both questions?

Dr. THIEL. In preparing for it, they should take the usual procedures: the precautions of having flashlights in their home, to have first aid kits, to have some emergency medical training, to know where the hazards are, where emergency help might be obtained in the neighborhood. They should have—let's say, in single-family dwellings—fire extinguishers, all-hazard types of fire extinguishers and a portable radio. They should take steps to attach their water heaters, if they're gas water heaters, to the wall, so that they don't turn over and become a source of flames—the pilot light.

There are efforts you can take to attach your building, if it's a residential structure, more adequately to the foundation to make sure that the cripples above the slab are well-placed by tacking plywood or putting on T-section reinforcements, among a number of actions.

Senator SCHMITT. Can somebody in that area go somewhere specific or write someone, in order to get this information?

Dr. THIEL. The city and county of Los Angeles and the county of San Bernadino have put out pamphlets to that effort that have been very widely distributed. In general, they are not being followed and not being seen by the people who need to know.

Senator SCHMITT. Is there any broadcast media utilization of this material?

Dr. THIEL. Very extensive, I'm told. But again, my understanding of the effectiveness of these communication mechanisms in actually causing people to act, is that they have not been particularly effective to date. This is one of the things we want to study very carefully to try and figure out how we can cause individuals and institutions to make these changes at their own behests.

Senator SCHMITT. If you had something in hand, something that everybody agreed was an adequate set of recursive criteria, which would lead you to predict an earthquake within a relatively short interval of time, have you worked out which you would want people to do in reaction to that prediction?

Dr. THIEL. I have. But it doesn't represent any kind of consensus at this point.

Senator SCHMITT. So there is not an agreed-to consensus of what that should be?

Dr. THIEL. No, sir.

Senator SCHMITT. And how you would inform the public as to what they should do, in the event of a prediction, and then how you would inform them of the prediction itself.

Dr. THIEL. Both of these questions are integral to the southern California prediction and planning program. I think one thing that I would really like to emphasize here is that for prediction preparedness, be it normal mitigation procedures or the emergency period following prediction, or following the event itself, it's extremely important for the Federal Government, the State government and local governments to act in concert and in reinforcement of each other's activities, rather than interfere with each other's activities.

I am of the opinion that unless our preparedness posture for earthquake response is improved in a cooperative consistent manner among these various levels, and components of government, that we'll very likely end up with situations where the different governmental units are running into each other and misinforming the public or informing them in contradictory ways or ways that are not entirely consistent, thereby causing the public to decide to take neither's advice.

So I believe it's very important in earthquake preparedness that whatever the Federal Government does it be done in consort and consistently with State and local governments. This is the precept behind the southern California emergency preparedness project, which I've alluded to earlier. Unfortunately, Dr. Ledbetter is not able to be here to testify on it.

Senator SCHMITT. Why is it taking so long to put together these kind of arrangements that we need to have? We've brought congressional attention to this several years ago. We're still more or less saying the same thing that we said several years ago, when the act was put forth.

Dr. THIEL. I think there are a number of reasons. First of all, there's a tradition of ignoring earthquake hazard issues, in California, particularly. But even more so, in other high risk areas, such as the Wasatch Front, or the New Madrid area, which have had very large events which could occur with a reasonably high likelihood. There is a tendency to want to downplay such cataclysmic, catastrophic events on the public side. Most politicians have been unwilling to take a position with respect to increasing earthquake hazard protection, because, after all, it's increasing expenses in the present for some future unspecific hazard.

Last, I'm not sure that there's been a history of cooperation between Federal, State and local governments on emergency matters, and of the State and local governments to trust each other, much less the Federal Government. So I think there's a history of involvements of different elements of governments, which tend to interfere with people coming to the table and reaching a consensus position.

Further, I would suggest that earthquake preparedness, properly pursued, cuts across virtually every interest of the community—commercial, industrial, educational, in terms of property rights, and in terms of individual rights. So it turns out, to be a microcosm of political and institutional problems, and it reflects those from a lower level. So it's not an easy environment in which to cause change.

Senator SCHMITT. It's particularly not easy, when you don't have strong national leadership on the political level.

Dr. THIEL. I would concur with that. It's also true that it's difficult when there's not strong local or State leadership, which until recently has been basically absent.

Senator SCHMITT. I presume that FEMA has looked at the reaction to various natural events such as the San Fernando earthquake and Mount St. Helens. The institutional reaction to those events, and tried to see how well we did. How well did other entities do, and what could be done in order to improve that reaction; is that true?

Dr. THIEL. That is correct.

Senator SCHMITT. Is there any summary information the committee could have, which shows what you have concluded as a result of those studies?

Dr. THIEL. I don't believe the critique has been finished on the Mount St. Helens response. But we could certainly make that available to you as soon as it is done.

Senator SCHMITT. What about the San Fernando earthquake?

Dr. THIEL. There is a critique from a number of years ago. I don't know that it is as germane now as it was 8 or 9 years ago.

Senator SCHMITT. Well, people haven't changed.

Dr. THIEL. But the governmental institutions have changed, both at the State and Federal levels.

Senator SCHMITT. What do you mean they have changed? There is still city government, Federal Government, and State and county government; most of the agencies are approximately the same.

Dr. THIEL. At the Federal level, no.

Senator SCHMITT. I think it would be very important to a group like FEMA to look back and see where people made mistakes in the past, and where people do things right.

Mr. CRAWFORD. Mr. Chairman, if I might interject. In the disaster response recovery program, the process is a standard one which is followed after every declaration. State and local people do get together with the Federal people and the private sector people, to assess the performance of the mechanism: How did it operate? How should it have operated?—with the goal of incorporating improvements in the future.

For example, I suspect that one of the conclusions leading to the combined application verification test process, which was employed in Texas and several other disasters in the past year, reflects the fact that critiques have shown that people have had great difficulty in applying for the various kinds of aid.

There was a decision made to try and combine the various applications into one process. That's a simple example of how the critique process resulted in changed policies and operational approaches.

The critique process is a well-established process in the response area.

Dr. THIEL. Furthermore, the changes in the Federal Disaster Relief Act, Public Law 93-288, derive to some extent out of the experience in the San Fernando earthquake. San Fernando, as serious as it was, really only represents a scratch on the arm, compared to the kind of event we're looking for.

Senator SCHMITT. I would agree. That's why I keep using it as an example. It gives you the first major indication of what's going to happen to you in a big one—but worse.

So if you have any summary information on those critiques, we would appreciate it.

Dr. THIEL. I might just add one additional item. The most recent earthquake of comparable magnitude impacts would have to be the Southern Italy earthquake, in January. There are those kinds of critiques going on now, on the Southern Italy response, including sending several U.S. teams there to investigate the response. So we can draw experience from it. The same is true for Japan. Japan is probably confronted with earthquake disasters, once again larger than we might expect in this country. We're making a concerted effort to go to school on their planning efforts and capabilities.

Mr. CRAWFORD. Mr. Chairman, also, while a number of Dr. Thiel's answers have been couched in terms of what's going on in southern California now; and while admittedly that represents the early stages of development of the kind of preparedness plans to which you refer; nevertheless we feel that there is significant momentum there. There is a motivation at the State and local level, to deal with this issue. And we view the southern California activity as perhaps a model or prototype approach to the complex institutional problems of getting this kind of preparation done elsewhere in the country, in other moderate to high-risk areas.

Senator SCHMITT. I have a question, gentlemen: Do you think we're doing enough research and research application in the predictive area?

Dr. THIEL. I believe that the President has presented a sound, well-balanced program for research. I must say that I think that we can use more of our resources for problem-focused mitigation and prediction projects. I think that's an area that could be enhanced. Particularly in southern California, we'd be well advised to concentrate more of our efforts in a mutually supportive way; particularly on the data collection side.

When you said "predictive research," you meant earthquake prediction research on the technical side, I presume?

Senator SCHMITT. Yes.

Dr. THIEL. That's how I understood it.

Senator SCHMITT. To take advantage of what we know, what other countries know, what's been done, what obviously could be done to actually begin to put together a prototype predictive system in a high-hazard area.

Dr. THIEL. The President's program of research allocates, on an interagency basis, about $16.5 million of the total $66 million program on earthquake prediction per se, and additional $11 million for the support of fundamental research and data services in support of prediction and other geophysical aspects of the program. I believe that this is a substantial program.

We, of course, could do much more. That's always the case in science. Particularly in southern California, I believe, there would be merit in considering, next year, the placement of the concentrated earthquake prediction information collection system in southern California.

Senator SCHMITT. Would you provide the committee with a list of other areas where you consider there to be hazards comparable to those faced by southern California?

I include in that respect any area along the San Andreas fault, in which there has not been a major earthquake.

Dr. THIEL. I'd be happy to provide that now, if you like.

Senator SCHMITT. We must move on. If you could supply that for the record, we'd appreciate it.

Unless you can take 10 seconds to read the list?

Dr. THIEL. I would just say that the current estimates are about 85 percent probability of a magnitude 6 or greater earthquake in the next 15 years in the Wasatch Front—Salt Lake City.

There have been several estimates, depending on how you manipulate the statistics, from 4 to 21 percent probability of a magnitude 8 or greater earthquake in the New Madrid area, in the next 20 years.

These are certainly two other very high-risk areas, to be added to the usual high-risk area, the San Francisco area. These would probably be the four principal high-risk, large-population areas.

Senator SCHMITT. What about Anchorage?

Dr. THIEL. I would certainly put that on the list. But fortunately, there aren't as many people there as in the other areas.

Senator SCHMITT. So that list relates to, also, the number of people?

Dr. THIEL. Yes, sir. The catastrophe potential regions. I suggest those are the four high-measured-risk areas now.

Senator SCHMITT. San Francisco, Los Angeles——

Dr. THIEL. The Wasatch front and the New Madrid area.

I certainly would also place the Boston and South Carolina areas—Boston, Mass., and Charleston, S.C.—as high-risk areas.

I would also suggest that the entire Commonwealth of Puerto Rico is a major risk, probably comparable to the aforementioned cities.

Senator SCHMITT. OK. Thank you.

One more: Do you handle volcano hazard mitigation out of the same shop?

Dr. THIEL. Yes, sir.

Senator SCHMITT. Are there any areas besides the Northwestern part of the United States, down through northern California, that you include as high volcano-risk areas?

Dr. THIEL. I recently attended a presentation by a volcanologist from the Geological Survey, Ray Bailey from the Reston USGS office who suggested there were several other high-risk areas in the country.

Certainly, one at high risk is the Yellowstone area in Wyoming. That presents particularly difficult planning problems because there are so many tourists in that area, and a relatively small capacity to absorb those people.

Second, he suggested some areas down in New Mexico and Arizona, which he felt were at substantial risk of eruption. Also, of course, Alaska and Hawaii are also high-hazard areas.

Senator SCHMITT. Thank you, gentlemen. We may have a few more questions for the record.

[The statement follows:]

STATEMENT OF ROBERT C. CRAWFORD, ACTING ASSOCIATE DIRECTOR, MITIGATION AND RESEARCH, FEMA

Mr. Chairman, Members of the Committee, my testimony will describe FEMA's activities in the Earthquake Hazards Reduction Program.

National earthquake hazards reduction program

Earthquakes pose a truly national risk. Great earthquakes have occurred in the last 300 years in Massachusetts, New York, South Carolina, Missouri, Washington, Alaska, Nevada and of course California. These events have affected not only those States but in some cases very large surrounding regions. All or portions of 39 States of the United States (see figure 1) and all our territories are at major or moderate earthquake risk with about 35 percent of our population residing in these areas. Among all the geophysical hazards none poses a threat to life and property similar to that posed by a single catastrophic earthquake. For example, one event which could occur in California could cause over $50 billion in property damage and a life loss of more than 20 thousand individuals, with many more being severely injured. We have been most fortunate in the last 100 years that our losses from earthquakes have been limited. Our understanding of the historical records and of current geophysical processes indicated that such continuing good fortune is highly unlikely.

This past year has been one of unprecedented initiatives in earthquake hazards reduction by the State of California, local governments and the Federal government. The State of California, through Assembly Bill 2202, has appropriated funds matching Federal commitments to improve earthquake preparedness in southern California. In addition, the Governor has just announced a major fiscal year 1982 initiative to improve earthquake preparedness (approximately $4.5M in new expenditures). The City of Los Angeles, after years of discussion, has adopted a hazardous buildings abatement program, and the Federal Government has instituted a major preparedness program. Federal programs have been integral to several of these California State initiatives and have provided a basis for others.

My testimony will be structured to: 1) examine the overall objectives of the National program; 2) discuss specific FEMA accomplishments and initiatives; and 3) examine specific issues which we believe should be considered in the reauthorization of the National Earthquake Hazards Reduction Program.

The purpose of the National Program (P.L. 95–124, as amended): ". . .To reduce the risk of life and property from future earthquakes in the United States by the establishment and mangement of an effective Earthquake Hazards Reduction Program. . ." is, in our judgment, still sound and comprehensive. The Act has set forth a broad set of objectives which are achievable and appropriate. In past years, several executive branch and legislative actions have resulted in the overall National Earthquake Hazards Reduction Program in which FEMA has the principal responsibility for the conduct and management of Federal agency activities. P.L. 95–124, the Earthquake Hazards Reduction Act, its extension through P.L. 96–472 and the resulting implementation programs, provide the basic framework for the National Earthquake Hazards Reduction Program. The National Security Council study, "An Assessment of the Consequences and Preparations for a Catastrophic California Earthquake: Findings and Actions Taken," and resulting assignments, reinforce the assignment of responsibilities for specific preparedness to FEMA. P.L. 93–288, the Disaster Relief Act of 1974, assigned responsibility for management of Federal recovery efforts from earthquakes and preparedness for such events to FEMA. Thus, our role is comprehensive, involving not only the coordination of earthquake hazards reduction policies and activities of Federal agencies and departments, but also the conduct of specific actions.

An analysis of the objectives of the National Earthquake Hazards Reduction Program indicates eight basic objectives. First, those which are the principal responsibility of FEMA:

Lead, plan and coordinate the National Earthquake Hazards Reduction Program (NEHRP).

Improve the capability of all levels of government and the public to respond to an earthquake or the prediction of an earthquake.

Develop, promulgate and encourage the application of specifications, building standards, design criteria, and construction practices to achieve appropriate earthquake resistance for new and existing structures within the Federal and private building communities.

Develop mechanisms for including earthquake hazards reduction activities in Federal, State and local governmental policies and programs.

Develop and disseminate information and knowledge useful in mitigating earthquake hazards.

Provide emergency and recovery assistance when earthquakes occur or are predicted and State and local resources are insufficient to respond.

In addition, other Federal agencies are assigned objectives to: Maintain a comprehensive program of research and development for earthquake prediction and hazard mitigation. Support the National Earthquake Hazards Reduction Program by participation in NEHRP activities and incorporation of earthquake mitigation and preparedness into mission programs, policies and activities.

While all agencies are directed to support research to one degree or another, the National Science Foundation and the U.S. Geological Survey support by far the vast majority of research in the area.

National Security Council Study

After viewing the destruction wrought by the eruption of Mt. St. Helens in Washington State in May 1980, the President became concerned about the impacts of a similar event of low probability but high damage potential, namely, a catastrophic earthquake in California, and the state of readiness to cope with the impacts of such an event.

As a result of this concern, an ad hoc committee of the National Security Council was formed to conduct a government review of the consequences of, and preparation for such an event. In addition to the Federal Emergency Management Agency, the Committee included representatives from the Office of Science and Technology Policy, the United States Geological Survey, the Department of Defense, the Department of Transportation and the National Communications System, at the Federal level. Representatives of State of California agencies, California local governments and consultants from the private sector also contributed. During the summer of 1980, the participants in this review prepared working papers on relevant issues and problem areas for the consideration of the ad hoc committee. Pertinent facts, conclusions and recommendations were reviewed with the Governor of the State of California. The President reviewed the ad hoc committee's findings and approved the recommendations for Federal action. A copy of the report, which summarizes the results of the assessment and notes these actions, is available for the record.

This assessment determined the state of preparedness of local, State and Federal government organizations to respond to a catastrophic California earthquake, the capability of the Federal government to provide substantial assistance to other levels of government in those cases in which it would be required, and identified actions that could improve the overall state of earthquake preparedness.

The assessment concluded that the Nation is essentially unprepared for the catastrophic earthquake in California that can be expected to occur in the coming decades. While response plans and preparedness measures may be adequate for the occurrence of moderate earthquakes, substantial steps need to be taken to cope adequately with the consequences of the occurrence of a catastrophic earthquake striking a large urbanized area in California.

Based upon this assessment, the Federal Emergency Management Agency has been charged by the President to provide aggressive leadership throughout the Federal Government and to serve as a focus for cooperation with California in preparing for predicted or unpredicted catastrophic earthquakes. Initial emphasis is being placed on southern California, where the U.S. Geological Survey indicates the current risk to be the highest. The damage which could result from potential events ranges from $20 to $70 billion in property damage and from 3,000 to 20,000 lives lost. Planning for this eventuality is one of FEMA's highest priority activities.

The following actions were taken at the Federal level as a consequence of this review:

The Federal Emergency Management Agency and other Federal agencies are strengthening significantly their research activities and efforts to implement comprehensive and detailed earthquake preparedness programs;

Federal agencies are increasing their efforts with State and local governments and voluntary and private sector organizations to prepare integrated preparedness plans to respond to the occurrence of catastrophic earthquakes in California and/or their prediction;

The Federal Emergency Management Agency is working with the State of California to develop and publicize appropriate self-help and lifesaving information; and

The Federal Emergency Management Agency and the State of California are developing an agreement which will enable the President to make Federal resources for lifesaving and humanitarian actions immediately available upon the occurrence of a catastrophic California earthquake.

Southern California earthquake preparedness program

While the National Security Council assessment just described was under way, officials from the California Legislature, California Executive Departments, local governments, and representatives of the private sector in southern California were developing an innovative, cooperative effort to enhance the public safety through improving substantiative preparedness planning and programs capable of responding to the occurrence or prediction of a catastrophic earthquake. Through their combined efforts a federated program has been developed in which State and local government, Federal government and the private sector are participating together. On September 25, 1980, the Governor of California signed a law which, among other things, provides for State participation in this cooperative program. The Act is contingent upon the availability of matching Federal funds. FEMA has thus far committeed $300K to the California effort, and expects to commit an additional $500K in the near future. The program is being managed by the California Seismic Safety Commission under the guidance of a policy committee with representatives principally from the local community. We are very pleased to be involved in this innovative approach to emergency planning. The essential premise of this undertaking is that no element of government has sufficient resources or capabilities to respond to the expected needs in time of an earthquake disaster. This realization is beginning to galvanize a coherent management approach among the actors which could serve as an interesting prototype for emergency preparedness undertakings in general. We are committed to use the results of this effort as the Federal earthquake response plan, given that it meets minimum requirements. We are hoping that the State and affected local governments will make a similar commitment. We feel that this partnership approach provides the strongest means of harnessing Federal, State and local talents and resources in preparing for a major earthquake in the southern California area.

Interagency committee on seismic safety in construction

A key element in the National Earthquake Hazards Reduction Program is the improvement of Federal sector building practices. The Interagency Committee on Seismic Safety in Construction (ICSSC), was established to act as the focus for the development of improved building practices and the underlying process for their application. Through the efforts of a large number of participants from diverse

Federal agencies the Committee has been very active this past year. I am pleased to report that the Committee has:

Completed development of a proposed set of building practices which is now being submitted to construction agencies for their review and trial application;

Completed an authoritative guide to estimate tsunami risk in coastal areas. Members of the Committee have participated in the national efforts of the Building Seismic Safety Council to develop improved building practices for application in the private sector; and

Nearly completed a major series of manuals on the analysis of the seismic hazards at building sites, including questions of risk analysis, ground vibration and local soil failure.

The manuals on analysis and tsunamic risk are unique and are not available from other sources. Thus, they have potential for utilization throughout the entire building community.

Building seismic safety council

The Building Seismic Safety Council (BSSC) was conceived in 1979 as an entirely new kind of instrument for dealing with the complex technical, social, economic, and public and private jurisdictional issues involved in developing and promulgating building earthquake hazard mitigation regulatory provisions that are national in scope.

Historically, regulation of the design and construction of buildings in the United States has had as its principal aim the protection of public health and safety; specifically, the protection of the public from the actions of the individual property owner. How the individual designed, built, operated, and maintained structures on his own property for his own use were not of public concern as long as the owners' neighbors and the public were not exposed to harm. Urban densities, rental of properties, frequent property transfers, and much more, have long since obliterated much of distinction between the isolated property owner and the using public insofar as regulation for health and safety are concerned.

The power to regulate building and buildings rests with the States under their police powers or with communities by State delegation of these powers. Generally, there is no vertical integration of the administrative organization adopting and enforcing building codes. Further, the building community itself is a large, diverse, highly competitive community supported by a very large number of independent organizations. The development of improved building practices has depended principally upon voluntary professional associations, universities and particular materials manufacturers. The building industry, and particular local building regulation is thus a complex of integral yet independent actors.

In large measure, it was in response to the complex building regulatory environment that the BSSC was created. By bringing together all of the needed expertise and all interested parties, public as well as private, it is intended that both technical and social and economic issues can be resolved, and that the jurisdictional problems will be overcome as well. The result will be authoritative guidance and assistance that is backed by a broad consensus.

During the past year the Council has completed an extensive review of the Applied Technology Council document "Tentative Provisions for the Development of Seismic Regulations for Buildings." A series of 198 recommendations for changes were made—a number that exceed expectations but emphasized the need for such a thorough review and analysis of the document before proceeding further. Balloting has now been completed among the membership. The results indicate that a large portion of these recommendations has been accepted. The second annual meeting of the Council was held during this balloting period and provided yet another forum for understanding and comprehensive discussion of the proposed changes. The Council has directed a trial design program which is intended to professionaly test the resulting design procedures to assure that they are technically sound, consistent, and lead to safe and economically feasible structures.

At the completion of the trial design process, it is expected that the resulting procedures will be adopted by voluntary code and standards organizations as well as by State and local governments as a basis for their regulation of the seismic safety of buildings. When this process is completed, the ICSSC intends to review the standards for potential adoption in Federal practices.

National earthquake hazards reduction program issues

The initiatives for the past ten years following the San Fernando earthquake in 1971, and particularly the research efforts of the past five years, have built a substantial basis of knowledge in earthquake hazards mitigaton. This foundation of knowledge has been developed by taking advantage of the individual initiatives of separate researchers working, by and large, in the areas which have the most scientific promise. Generally, this mode of scientific development has been, in our judgment, the appropriate research management strategy. We are now at a point in which fundamental management decisions must be made concerning future directions of the program. Past efforts have focused on the development of new knowledge—a process far from complete. However, there is sufficient knowledge and experience now to initiate a larger portion of project oriented activities designed to develop, test, and demonstrate the efficacy and economy of earthquake hazards mitigation strategies. This is not to say that there needs to be a decreased emphasis on basic and applied research or earthquake hazards mitigation—indeed we are on the potential threshold of major breakthroughs in seismic knowledge. But, it is to say that the time is ripe to augment these efforts with systematic projects to more directly affect the public's earthquake safety. In part, some such efforts have already been initiated: the southern California Preparedness Project, the Building Seismic Safety Council efforts to improve building practices (based on NSF initiatives) and the U.S. Geological Survey's focus on earthquake prediction research activities in southern California. These are representative of the transition of the Earthquake Hazards Reduction Program from a research phase into a development phase.

We believe that now is the time to initiate a transformation of the earthquake program from the individual investigator research program to one which has a specific project orientation. Such a changed focus should not imply that there should be decreases in individual scientific investment support. We see that support being closely linked into this new project phase. In our judgment, movement into the specific project phase is a key issue before the Congress.

Closing

Mr. Chairman, we feel that FEMA's activities in the area of earthquake hazards reduction offer substantial potential for improving the ability of the United States to mitigate the consequences of destructive earthquake activity. We are committed to an active, aggressive program in this area, and will continue to emphasize our partnership approach as we work with other Federal agencies, State and local governments, and the private sector in strengthening our country's plans and preparedness posture. We believe that FEMA has carried out our designation as the lead agency for the National Earthquake Hazards Reduction Program well even in the face of the heavy competition for the limited resources available to the Agency.

Thank you, Mr. Chairman.

FIGURE 1

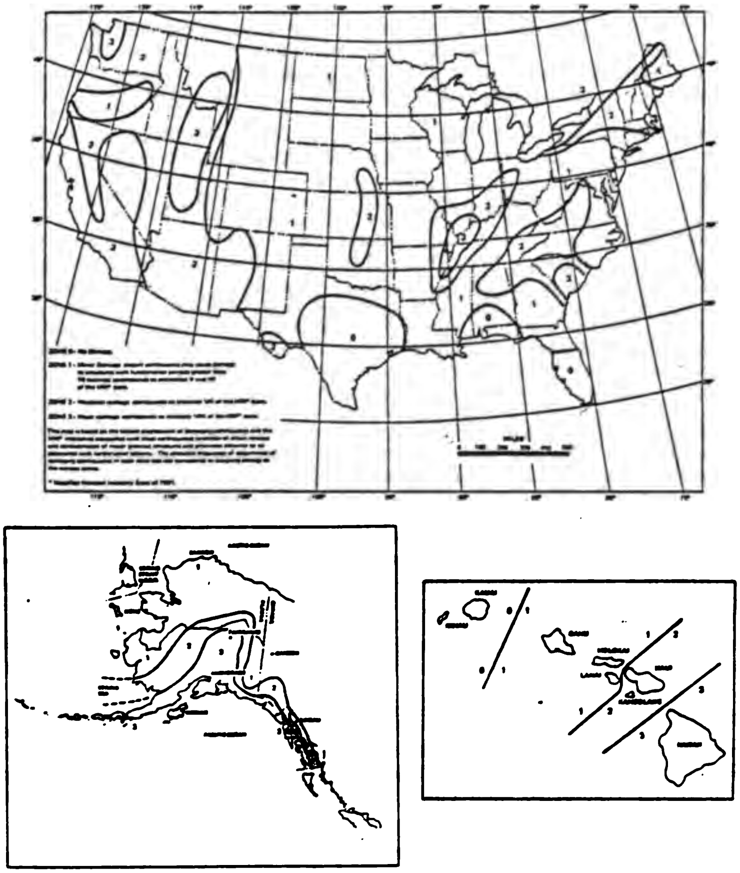

Figure 1: Seismic Risk Maps for the United States

Zone 0 - No damage

Zone 1 - Minor

Zone 2 - Moderate damage

Zone 3 - Major damage

[The following information was subsequently received for the record:]

QUESTIONS OF THE COMMITTEE AND THE ANSWERS THERETO

Question. What is the status of the annual report which was due on the first of the year?

Answer. The pressing demands of the Southern California Preparedness Program and constrained staffing have prevented delivering this report on time. Efforts are now underway to prepare this report and we hope to deliver it by June 1. We have instituted procedures to assure timely preparation and delivery of the next annual report.

Mr. CRAWFORD. Have there been any delays in developing earthquake preparedness plans in California caused by the absence of a defined policy of intergovernmental sharing?

ANSWER. No. Federal, State and local agencies are cooperating well and there appears to be no need at this time for a specific defined policy.

Mr. CRAWFORD. The act requires periodic review with non-Federal participation of the program plan in its entirety. What has FEMA done towards this requirement?

ANSWER. FEMA has yet to establish an external advisory panel to review our National Earthquake Program Plan. The National Science Foundation and U.S. Geological Survey have such panels which periodically review their programs and specifically have reviewed their program plans prior to their submission to FEMA. FEMA will establish such a panel when funds become available.

Mr. CRAWFORD. Would you be more specific, with an example perhaps, with regards to the shift in research management strategy?

ANSWER. Currently, the external grants programs of NSF and USFS respond to requests prepared by individual investigators to conduct research selected on specific topics they select. The agencies identify broad topical areas but propose little, if any, structure on specific investigations. Under a project system of research management, the agency would not only define a specific objective (e.g., strengthening existing hazardous masonry structures) but identify specific investigations which must be conducted to achieve these objectives (e.g., 1. Bonding strength experiments for brick. 2. Attachments of wood diaphragms. 3. Effects of retrofitted bond-beams on structural integrity.) Such specific investigations could, and generally would, be conducted by several investigators whose activity is coordinated by the agency or a management contractor. Both agencies have initiated a few such projects. The net effect would be for such projects to be more sharply focused on achieving overall program goals.

Question. If adopted, will such a shift deprive the basic studies of needed support?

Answer. We have proposed that such a strategy be adopted for increments to the program and that the basic studies portion of the program remain intact. If agencies were required to adopt this method of research management without receiving additional budgetary resources, then basic studies support would, of necessity, be reduced.

Senator SCHMITT. The next witness is Dr. Robert Wesson, Assistant Director of Research, U.S. Geological Survey.

You can feel free to summarize your testimony. It will be in our record, in its entirety.

STATEMENT OF DR. ROBERT L. WESSON, ASSISTANT DIRECTOR FOR RESEARCH, U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR, ACCOMPANIED BY DR. JOHN FILSON, CHIEF OF EARTHQUAKE STUDIES

Dr. WESSON. Yes, sir. Mr. Chairman, I'm pleased to appear before the Senate Subcommittee on Science and Technology and Space, to review the progress of the program carried out by the U.S. Geological Survey on the Earthquake Hazard Reduction Act.

I have here with me Dr. John Filson, who is Chief of Earthquake Studies within the U.S. Geological Survey, and has the responsibility for day-to-day management of our earthquake programs.

In the written statement we have provided for you, we describe in some detail our roles, accomplishments, and current emphases, and various elements of our activities under the Federal implementation plan resulting from the Earthquake Hazard Reduction Act.

In general, our responsibilities under this act are to conduct research on the nature of earthquakes, earthquake prediction, earthquake hazards evaluation, and do seismicity, and carry out a number of activities that move that research toward application.

Briefly, I'd like to summarize for you today some of our accomplishments under this program.

First, we believe we have improved the capability to make national seismic risk maps, and to give quantitative evaluations of areas under risk throughout the country.

Second, we believe we have made significant progress in improving estimates on the average recurrence rates of large earthquakes in various parts of the Nation; not only in California, but in Nevada and in the Wasatch front in Utah; and some success in the New Madrid area of the Mississippi Valley.

Third, we've made significant progress in the acquisition and analysis of records of strong ground shaking near the sources of damaging earthquakes.

As you may know, Mr. Chairman, some of these results have led to substantial rethinking in the engineering community about the magnitude or the absolute value of the kind of ground shaking we should experience, and the ways to design buildings to defend against that ground shaking.

Fourth, we've developed, partially through support by the U.S. Geological Survey programs and partly, of course, through the National Science Foundation programs—abilities for long-range earthquake forecasting, based on recognition of so-called seismic gaps.

Notably, this concept in the United States has been applied to a region in southeastern Alaska near Yakataga, where we believe a seismic gap has been recognized. And in fact, we have discussed with the State of Alaska our feeling that this is the most likely area for a large earthquake in the continental part of Alaska, in the next few decades.

Senator **Schmitt**. Excuse me. Did such a gap exist prior to the Good Friday earthquake?

Dr. **Wesson**. Yes, Mr. Chairman.

Senator **Schmitt**. That would have been considered a gap prior to that?

Dr. **Wesson**. Mr. Chairman, since about the turn of the century, the whole region from Kamchatka along the Aleutian arc, through the Cook Inlet, and down along the southeast coast of Alaska—nearly to Vancouver Island—has ruptured in a sequence of large earthquakes.

These earthquakes have tended to indicate ruptures along parts of this arc. Subsequent earthquakes in the sequence have filled or extended gaps—well, subsequent earthquakes have either filled gaps or extended the zone of rupture from previous earthquakes.

The Good Friday earthquake did, in fact, fill one of those gaps. There are only two potential areas left that have not broken since the beginning—actually, three areas that have not broken since the beginning of the century: One is in the extreme eastern part of the Aleutian arc, almost at Kamchatka, where there's some question about whether we should ever expect big earthquakes because at that point the rate of plate motion, the direction of plate collision, is not more-or-less perpendicular to the arc, but is at a skewed angle to the arc. So there may be some anomalous activity there.

The second area is in the Shumigan Islands, which I think are just on the southwestern end of the Alaska peninsula. We're not sure whether this is a true gap or not, because this was possibly filled in by a big earthquake in the 1930's.

The third area, that I mentioned a moment ago, is the Yakataga gap which, in effect, fills the part of this whole region between the Good Friday earthquake on the west, and the 1957 Fairweather fault earthquake on the east.

Our attention was particularly focused on this gap by an earthquake in February 1979, near Mount St. Elias, which is just at the very eastern end of this gap.

Subsequently, there was a lot of argument about the actual plate boundary right there; whether it's on the shore or beneath the sea. But it's pretty clear that this area has not been struck by a great earthquake since at least 1899. And, consequently, we believe it's the highest probability.

Sixth, Mr. Chairman, we believe we've accumulated quite substantial laboratory and field efforts that slow premonitory fault slip or fault zone weakening precedes some, if not all, major earthquakes by a few days or a few hours. This may be a very important observation, and a key to short-term earthquake prediction.

Seventh, we believe we've got a good system developed for the provision of earthquake information and data, through our national earthquake information service and its supportive seismographic networks.

Finally, we believe we've made significant progress in the correlation of local seismicity associated with the filling of reservoirs with the water depths and the filling rates and the actual process of fluid movement beneath these large reservoirs.

There is additional research work which we believe is quite exciting, and we can discuss it in some detail later, and some of its applications.

However, I'd like to use my remaining time to address two specific questions you put to us in your invitation of March 24, 1981.

First, Mr. Chairman, we're basically comfortable with the Federal Emergency Management Agency (FEMA), in the lead role to plan and coordinate national earthquake hazard reduction programs. Heretofore, this coordination has been conducted on a rather informal basis, depending strongly on the goodwill and personal contacts between the managers of FEMA, NSF, and the USGS.

We understand steps are being taken to place this coordination on a more formal basis, through periodic scheduled meetings of the principals involved from each agency.

We certainly support this effort.

Second, your invitation also asks us to indicate what work is being accomplished by the program, to enhance the Nation's state of preparedness for a major earthquake, relative to the research aspects of this program.

I would like to confine my comments to the activities of the U.S. Geological Survey, and begin very briefly by reviewing our management strategy.

In 1980, our staff published about 200 papers and articles and reports on investigations relating to earthquake programs.

In addition, we have about 100 external grants and contracts which have published, at this very second, an unknown number of similar reports, in a similar time period; but approximately of the same order. These investigations all together are guided by a 5-year plan, with specific goals, objectives, and tasks, directed toward our responsibilities in meeting the Nation's earthquake hazards.

Solicitations for external work are based on this plan, when each element of our program is assigned to a manager who coordinates both internal USGS and external contractual activities. Within the U.S. Geological Survey—in fact, within the staff of the Office of Earthquake Studies, we have an individual whose title is the Deputy for Research Applications. One of his clear responsibilities is to seek out new and further develop existing mechanisms for coordinating research; and, particularly, delivery of our products and results within the U.S. Geological Survey as a whole.

We have an organizational element called the Office of Earth Science Applications, and its principal job is to develop further mechanisms for working, particularly with State and local governments, to act as a transfer mechanism for the findings of the U.S. Geological Survey.

However, we realize that research papers and management diagrams do not assure increased national preparedness for major earthquakes.

We also realize that a major step toward this goal is communicating our results with the Federal, State, and local officials.

As an example of our activities toward meeting this important need, we have cosponsored, organized, and published proceedings of a conference in January 1980, in Los Angeles, on the problems associated with responses to earthquakes, and particularly earthquake predictions.

We are planning a similar conference for the Eastern United States this fall.

We have carried out a number of similar kinds of conferences involving Federal, State, and local government representatives, and the private sector. Examples include: a workshop held on evaluation of reasonable seismic hazard risk; and another workshop on earthquake hazards in the Puget Sound, Washington, area.

Through this type of direct interchange with the community of decisionmakers responsible for taking the actual local government actions to mitigate earthquake hazards, we believe the Nation is becoming increasingly aware of, and is becoming increasingly better prepared to meet, the earthquake threat.

That's where the results of our research programs have been and are being felt—in the revision of building codes, in community zoning, the development of standards for Federal construction, in the siting, design and review of critical facilities, and in direct advice to the Federal, State, and local governments.

Finally, within our earthquake prediction activities, we have established experimental networks of geophysical instrumentation for primarily the faults in California. Although these networks are not operational in the sense that we are not in the business of making routine predictions, but data are reviewed periodically, and data that may show anomalous activities will be watched closely.

I'd like to give you one example which illustrates the way in which we're beginning to move from a very experimental mode in the area of earthquake prediction to a routine or systematic kind of effort. On the Sunday before Memorial Day, last May 1980, two earthquakes of approximately magnitude six occurred within 3 hours of one another near the Mammoth Lakes area in eastern California. These earthquakes triggered rock slides and avalanches in the nearby mountains in Yosemite National Park, injuring several people. Of course, our networks recorded the first earthquake, but before the second had occurred, our scientists were reviewing the situation in Menlo Park, Calif., and the Director of the Geological Survey had been notified.

Our concern increased with the second large earthquake because data recorded previously in the studies of the seismic history of this whole region indicated that large earthquakes in that particular region tend to occur in swarms or sequences of many earthquakes of similar magnitude. Within a few hours, working through the emergency response elements of our Office of Earth Science Applications, we issued a hazard watch to the States of California and Nevada indicating that further strong ground shaking from subsequent earthquakes might be expected within the next few days.

Two days later, a third earthquake of magnitude six occurred in this region. We do not claim that this example of preparedness saved a lot of lives or resulted in the avoidance of a major disaster. Only a few schools and trails were closed. Nevertheless, the following should be noted.

First, we had a body of previously recorded data from the region with which to compare current recordings.

Second, the current recordings from the local seismograph network were being transmitted to our research center at Menlo Park for immediate analysis. The scientists reported for duty to conduct the analyses that revealed the aftershocks from the first two earthquakes did not decay in frequency or magnitude.

Mr. Chairman, normally if you have a large earthquake, both the magnitude and frequency of subsequent aftershocks will decay very quickly. This was not the case in this particular swarm.

Third, administrative procedures were in place, and responsible officials were identified—the Federal and State governments through which a warning could be issued.

Finally, these procedures and officials responded effectively to the situation, even though it developed during a 3-day weekend, over the Memorial Day weekend. Although this is but one minor test of our current preparedness, it is doubtful that the sequence described would have taken the course it did without the scientific, technical, and preparedness advances made thus far under the National Earthquake Hazards Reduction program.

Of course within the last year we've gained considerable experience of a similar nature with regard to Mount St. Helens in which, as you are probably aware, our people first issued books and pamphlets describing the volcanic hazards at Mount St. Helens. This material had been transmitted to the local officials. Workshops had been held. But frankly not much had been done until the end of March, 1980 when seismograph networks funded by the Geological Survey and operated cooperatively with the University of Washington, observed an anomalous swarm of earthquakes immediately beneath Mount St. Helens. This initiated a whole series of investigations, not only by seismologists and geophysicists, but by volcanologists who converged on Mount St. Helens and began to make the observations that led to the recognition of the large bulge in the north side. All during this time communications were being made with and close contact was being maintained with the Governor of Washington State and with the appropriate Federal officials, namely the Forest Service and FEMA, and the State and local officials including the sheriffs' departments.

A system of hazard zones was set up around the mountain, resulting in the evacuation of some people so that when the eruption actually did occur on May 18, many lives were saved.

This is not, of course, a strict analog of the earthquake experience which we may expect, but we believe that we gained significant experience in dealing with the predictive kind of situation.

Finally, Mr. Chairman, we look forward to our participation in future enhancements of the Nation's state of preparedness for a major earthquake.

Thank you.

Senator SCHMITT. Thank you very much.

Do you believe if resources were available, it would be appropriate to begin a major focused project on some portion—obviously high-risk portion of the San Andreas fault and attempt to provide a predictive system of looking at all of the variables that seem to be appropriate?

Dr. WESSON. Yes, sir, Mr. Chairman, I do.

Senator SCHMITT. Do you think the state of technology and understanding is to the point where that would be a worthwhile exercise?

Dr. WESSON. Mr. Chairman, let me back up just a little bit. I believe that we're in a state with regard to earthquake prediction approximately analogous to when Robert Goddard flew his first liquid fuel rocket. We're getting to the point, I believe, where we need to undertake some larger scale experiments. We have developed a number of networks throughout southern California. We've studied those observations; we've studied observations made in other parts of the world. We're reaching the point where we need to consolidate our experience in all these different projects carried out within the Geological Survey and within the academic and industrial communities and to put together what might be called a prototype, or prototype operational, kind of system such that we have the uniform capability for collecting data, a somewhat more rapid mechanism for collecting these data and for processing and analyzing them.

So I'm not sure we're prepared to go into the routine earthquake prediction business, but I believe we're ready to take the next step in the logical progression from the simple kind of experiments to more of a prototype.

Senator SCHMITT. Has that prototype been designed in any way?

Dr. WESSON. I wouldn't say that we've taken or made much progress in designing that. We have begun to sketch out what we believe that should be. We are undertaking some discussions within the Geological Survey about the finances that would be required to do that. In spite of the budgetary climate, we believe we will make some proposals through the regular budget process for fiscal year 1983 to begin implementing that kind of system.

Senator SCHMITT. That, of course, would be site-specific.

Dr. WESSON. It would be site-specific, Mr. Chairman, to the extent we would focus our efforts in southern California.

Senator SCHMITT. Would the system you would design there have limited or great applicability to, say, the New Madrid system or the San Francisco system?

Dr. WESSON. I believe, Mr. Chairman, the system that we would design for southern California would have applicability elsewhere, but it principally would be focused first on the strike-slip kind of tectonic regime that we see in southern California. We would tend to emphasize the number of measurements of horizontal deformation and so on which might not be applicable, say, in New Madrid.

Senator SCHMITT. If you had to pick one or two major breakthroughs in the research over the last 3 years, what would they be in terms of new understanding that would lead to predicting—appropriate to predicting?

Dr. WESSON. I have a couple of my own, Mr. Chairman. Maybe Dr. Filson would like to add some of his.

I believe one of the most exciting breakthroughs that we've made over the last few years has been, first, our ability to gather recurrence data on large faults for past earthquakes. Some of this has been accomplished as long as 10 years ago, but we have begun to refine these techniques and develop them to the point where, for example, along the southern San Adreas fault we are able to recognize about eight large earthquakes in the last 1,200 years, spaced out at approximately 140 years. This is important not only for just estimating the risk over the long term, but indicating to us where we are on the earthquake cycle for that particular region.

This location that I'm referring to is in an area where the last large earthquake was in 1857. So based on past statistics, the occurrence of the earthquake in 1857, we can, in fact, make a probablistic prediction about future large earthquakes along that part of the San Andreas fault. That is the figure you have probably seen quoted in the National Security Council study—namely, that we would estimate there's a probablity of about 50 percent that such a large earthquake, a repeat of the 1857 earthquake, would occur within the next 30 years. I think that gives us a really important building block for shorter term prediction.

Second, we have, as a result of the increased funding for this program, beginning in fiscal year 1978—have been able to undertake some new kinds of investigations which were not possible in previous years. A significant number of these have been investigations in drill holes. Commonly geologists and geophysicists get the bulk of their information first of all, from the surface of the earth, and then we always want to get drill holes. Most holes are not drilled for scientific purposes but in search of oil, mineral deposits, and so on. Commonly they're not in the right spots and don't have the right parameters to conduct scientific investigations.

As a result of the investigations over the last couple of years, we have drilled some of our own drill holes. We have developed techniques for using other people's drill holes if they're in the right place, and we've been able to make some systematic measurements of the state of stress in southern California, using the technique of hydrofracturing. In this technique you inject fluid, and you watch the pressure at which the cracks begin to form, and you note their orientations using an instrument called a televiewer which can determine prefracturing cracks and postfracturing cracks and determine the orientation of the cracks. So we're able to actually measure the magnitude and orientation and stress, on the site. We'd like to do more of this work, but of course it's very expensive.

Third, we have begun to make quite significant progress in the area of horizontal strain investigations. Beginning in the early 1970s, we began a program of systemmatically surveying, using laser devices—a number of lines crossing the San Andreas fault in southern California, in fact extending into northern California and parts of Nevada. These data—we survey these lines annually, and we've begun to observe, over the first several years in fact—for about the first 6 to 8 years of observation, a very constant strain pattern.

Beginning in about the fall of 1978, we began to note some anomalies, and since that time, we've seen a number of rather strange anomalies in this pattern of strain—varying strain rates, in fact, and changes in direction.

Mr. Chairman, prior to the fall of 1978, we saw basically a north-south compression with little change in the east-west direction—basically a north-south compression. Beginning in 1978, we saw a pattern of strain which basically was a north-south compression plus a shearing along the direction of the San Andreas fault. In fact, another way to look at it is, we began to see an east-west extension in such a manner as to reduce the normal stress across the San Andreas fault, and from a rock mechanics point of view this suggested we were moving into a regime in which an earthquake would be more likely.

Then we saw a reverse on this, and now we've seen a reversion to this pattern of east-west extension. Would you like to say something?

Dr. FILSON. We haven't seen a complete reversal of the pattern to return to east-west extension in all of the networks. The networks are such that they're measured approximately once every year, and the results that are in from one of the networks does show a reversion east-west extension.

I might point out, though, Mr. Chairman, that associated with these—I think it's significant that we've seen a rapid change in the strain rates in these networks, which in the previous 8 years we didn't see. The investigators involved in making these observations were about ready to give up on the idea that it was a fruitless avenue to pursue.

During the same period of time, though, the last few years, we have seen these rapid strain variations. We've also seen a significant increase in the seismicity in southern California. If you take southern California, defined by region from San Francisco Bay west to Yosemite, during that period in the last 10 years, there have been, say, 50 or so magnitude five events in that region. But 25 of those events have occurred in these last 2 years, during the time we saw these strong variations in crustal strain.

Dr. WESSON. During the same period of time, we've begun to see three things. We've seen the abnormal or anamolous changes in the strain accumulation—type of strain. Second, we've seen an increased rate of seismicity, including such large earthquakes as the earthquake of February 1978. And throughout this time, we've also seen some anamolous changes in the radon gas quantity in some wells.

So we've——

Senator SCHMITT. Let me ask you, Do these 25 events that you have seen and others—do they tend to follow the strike-slip component or some other extension or pressure component in the fault system?

Dr. FILSON. In general, they tend to follow the strike-slip components.

Excuse me, but Mammoth Lakes are of the normal faulting type.

Senator SCHMITT. North-south normal faulting?

Dr. WESSON. Right. So I think these points that I've outlined, first the increased knowledge——

Senator SCHMITT. Excuse me. Mammoth Lakes. That was last year, right? Was that in the period of extension?

Dr. FILSON. Yes, sir. It was in the period of rapid changes in the strain.

Dr. WESSON. In summary, Mr. Chairman, the occurrence intervals give an idea of the seismic cycle, the measurements are beginning to give us some idea of actual processes and the measurements of stress in situ. Thirdly, the geodetic work has finally proved to be possible and proved to show what we considered geophysically significant data, which is related to the seismicity process.

So I believe these are all three quite significant scientific steps forward toward earthquake prediction.,

Senator SCHMITT. That's very interesting. Other than adding to the networks which you've described, is there any other area or areas of technology that you would like to see applied for correlation with the networks you already have? When I say "networks," I'm including the strain measurement networks as well as the radon and other measurements.

Dr. WESSON. First, with regard to the kind of prototype system, we'd like to systematize a number of these observations.

Senator SCHMITT. Would you like to add watching gophers or what?

Dr. WESSON. We've had some experience with ground squirrels, Mr. Chairman.

Senator SCHMITT. I'm being a little bit facetious.

Dr. WESSON. Let me make my response. Dr. Filson then can add his remarks. It seems to me that it's very important that we consolidate our gains in the geodetic areas. We would like to make these measurements more frequently than once a year. The way they're done now is quite time-consuming and expensive. We set up a geodolite on one mountain peak, shoot it out to a set of retroreflectors. In order to get the accuracy needed, we must fly that line with a helicopter of a fixed wing aircraft to make corrections for the temperature. So this is an expensive, time-consuming process.

We have been working to develop a multicolor laser device, such that these operations could be done more efficiently and on a more routine basis. We've had some experience.

Senator SCHMITT. You mean with the multicolor you could sort out and eliminate the effects that one color would give?

Dr. WESSON. That's exactly right. Unfortunately, the devices that are under development now have somewhat reduced range. We can get lines as long as 30 kilometers with the single color laser. The two-color laser seems to be limited to a 10 kilometer or maybe a bit more. We've had one prototype, one such instrument working near Hollister within the last year; however, we've been trying to get more of these instruments, but we've run into a lot of development problems with our contractor. We hope to sort those out. We're optimistic that over a slightly longer time frame, we'll be able to use space-based techniques. There's a system called the Global Positioning Satellite System which, in principle, with a fairly small box and small antenna, we could be measuring in real time, relative motions, throughout southern California.

Senator SCHMITT. That would give you sufficient motion accuracy?

Dr. WESSON. Mr. Chairman, the designers of the system and some of the people in the geodetic research community that we've supported, for example, Shapiro, at MIT, believe that this is true. We would like to see it in actual practice. We are having continuing discussions with NASA and the Defense Mapping Agency and the National Geodetic Survey toward the development of this system.

Senator SCHMITT. And you're dealing with the civil component of that system?

Dr. WESSON. That's correct, Mr. Chairman. We need to have accuracy of a centimeter or so over kilometers or tens of kilometers.

Senator SCHMITT. Relative accuracy?

Dr. WESSON. Relative accuracy. I don't believe—I'm not involved in these high level discussions, but it's my impression that that's not a particularly high priority for the noncivil applications of this kind of system, but we're hopeful that we can ride along on this quite expensive effort being carried out.

Senator SCHMITT. Gentlemen, we must proceed. We have a few more questions for the record.

Dr. WESSON. We'd be delighted to answer additional questions for the record.

Senator SCHMITT. Thank you.

[The statement follows:]

STATEMENT OF DR. ROBERT L. WESSON, ASSISTANT DIRECTOR FOR RESEARCH, U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

INTRODUCTION

This statement describes the program that the U.S. Geological Survey conducts under the Earthquake Hazards Reduction Act of 1977 and its reauthorization in 1980. It is submitted in response to the invitation of March 24, 1981, of the Honorable Harrison H. Schmitt to the Acting Director of the Geological Survey to participate in a hearing on the reauthorization of the Earthquake Hazards Reduction Act of 1977. It is requested that this statement be included in the record of the hearing.

Purpose and scope

This statement reviews specific responsibilities assigned to the Geological Survey under the Earthquake Hazards Reduction Act. It summarizes the goals, accomplishments, and current emphases for each element of our program designed to carry out these responsibilities. Finally, it describes briefly our management strategy for carrying out our work and for improving the dissemination and implementation of our results.

Implementation responsibilities

The Geological Survey, with the Federal Emergency Management Agency and the National Science Foundation, is heavily involved and committed to the national effort to mitigate earthquake hazards. We are charged with developing a comprehensive, well focused program of research that will improve the Nation's capability to mitigate earthquake hazards. Our immediate goal is to achieve scientific results that will give all levels of government and the private sector the opportunity to improve earthquake hazards mitigation, engineering, and planning practices leading to a substantial reduction of social and economic losses from future earthquakes.

The Geological Survey is responsible for implementing five specific tasks outlined in the National Earthquake Hazards Reduction Program. They are:

(1) To conduct research on the nature of earthquakes, earthquake prediction, earthquake hazards evaluation, and induced seismicity.

(2) To prepare national seismic risk maps.

(3) To evaluate earthquake hazards on a regional basis.

(4) To provide data and information on earthquake occurrences and hazards.

(5) To evaluate earthquake predictions with the advice of a National Earthquake Prediction Evaluation Council.

A sixth task—to acquire, analyze, and disseminate strong ground-motion data—is performed by the Geological Survey for the National Science Foundation. We believe that each of these tasks plays a critical role in preparing the Nation for future damaging earthquakes.

To manage and allocate the resources available for these tasks we have established five program elements. These are: Earthquake Hazard and Risk Assessment, Earthquake Prediction Research, Earthquake Data and Information Services, Induced Seismicity, and Earthquake Hazards Warning and Information Dissemination.

Below we describe briefly some of the accomplishments and current activities in each of these elements.

EARTHQUAKE HAZARDS AND RISK ASSESSMENT ELEMENT

The goals of this program element are to identify the potential for ground shaking, surface faulting, and earthquake-induced ground failures on a national and regional basis, to assess the risk from each hazards, and to devise predictive capabilities and mitigation strategies. An important part of the research is directed toward providing knowledge about the cause of each earthquake hazard, its severity, rate of occurrence, and physical effects. Data and information are provided to users so that they can reduce earthquake losses through improved design, better planning, and damage mitigation actions.

Accomplishment

The most significant research accomplishments of this program element include:

Improved definition of the average rate of occurrence of earthquakes in various parts of the Nation.—For example, geologic and seismological evidence suggests that, on the average, California experiences 3 moderate earthquakes about every 10 years and a great earthquake about once every 100–150 years. In Utah, although no moderate or large earthquakes have occurred since 1847 when the area was settled, geologic evidence suggests that such earthquakes recur every 50–430 years along the 370 kilometers long Wasatch fault zone. Geologic data and seismic reflection profiles near New Madrid, Missouri, show that large destructive earthquakes, like those of 1811–1812, happen about once every 600–700 years.

Improved national seismic risk maps.—Calculations for probabilistic maps of the hazard from ground shaking hazard expected at sites underlain by rock during exposure times of 25, 50, and 250 years have been completed for the conterminous United States and Alaska. The hazard from ground-shaking is expressed as peak ground acceleration and as peak ground velocity, two indications of the nature of ground shaking. Such maps are needed to establish and improve building codes.

Acquisition of ground-motion records from ground sites near a causative fault and at locations within a building experiencing damage.—The 1979 Imperial Valley earthquake has provided us with significant new data on two important topics: (1) the ground shaking levels and variations from 13 strong ground-motion stations close to the causative fault, (2) building vibrations from the onset of shaking to failure from the unique data sample of 13 records obtained within the 6-story Imperial County Services building. Experts have estimated that it would cost at least $7 million to duplicate experimentally these data acquired within a minute during the Imperial Valley earthquake.

Loss estimates for possible catastrophic earthquakes in California.—In 1980, the Geological Survey participated in a study for the National Security Council *ad hoc* Committee on Assessment of Consequences and Preparations for a Major California Earthquake to evaluate possible losses from catastrophic earthquakes in California. Loss estimates for a repat of the 1906 San Francisco earthquake on the San Andreas fault are: Up to $38 billion in damages to buildings and contents and as many as 11,000 deaths and 44,000 hospitalized. A magnitude 7.5 earthquake on the Newport-Inglewood fault in southern California could cause corresponding losses of up to $69 billion and as many as 23,000 deaths and 91,000 hospitalized.

Probability of occurrence of a major earthquake in California.—On the basis of geologic and geophysical evidence, the aggregate probability for a catastrophic earthquake in the whole of California in the next 3 decades is in excess of 50 percent. Along the southern San Andreas fault alone some 30 miles from Los Angeles, the probability of a great earthquake is currently 2–5 percent per year and about 50 percent in the next 30 years. The annual probability of a great earthquake along the northern San Andreas fault near San Francisco is about 1 percent. Other fault systems, such as the Hayward fault of the eastern San Francisco Bay region, are also capable of generating large destructive earthquakes. The probability of smaller, but still damaging, earthquakes occurring on each fault system is even greater.

Current emphases

Research tasks receiving priority emphasis include the following:

Establish an accurate and reliable national earthquake data base with standard methods of locating earthquakes, assigning magnitudes, and estimating uncertainties associated with these parameters.

Publish probabilistic maps that represent the ground-shaking hazard nationwide in a uniform manner.

Prepare maps showing hazard and risk assessments for selected regions of the United States using more detailed information such as geologic information about earthquake recurrence rates, seismic source zones, and the effects of seismic wave attenuation and local ground response.

Delineate and evaluate earthquake hazards and risk in earthquake-prone urban regions of the United States, including Los Angeles, San Francisco, Salt Lake City, St. Louis-Memphis, Charleston, and Boston.

EARTHQUAKE PREDICTION ELEMENT

The goal of this program element is reliable, short-term prediction of the magnitude, time, and location of major earthquakes. This research effort should also provide a physical basis for reliable earthquake predictions through the understanding of the mechanics of faulting. Research includes field, laboratory, and theoretical investigations of premonitory phenomena, earthquake mechanisms, and geological characteristics of specific fault zones.

Accomplishments

The most significant accomplishments of this program element include:

Seismic "gap" hypothesis well established.—Recurrence intervals for great earthquakes along crustal plate boundaries can be specified given historical seismicity information on a given boundary segment and nearby segments. This is, in fact, a long-term forecasting technique for the next major earthquake on a fault segment. Although the time of this event can be estimated only very roughly, it can be used to focus research efforts on areas of high earthquake potential.

Regional strain variations associated with increased seismicity.—In southern California rapid variations in crustal strain during 1979–1980 have been observed using accurate surveying techniques. At the same time southern California has experienced a striking increase in seismicity. Such regional strain variations and seismicity increases have preceded large earthquakes in other parts of the world. These phenomena may indicate that a seismic "gap," such as exists in southern California, will be filled by a major earthquake within a few years.

Fault zones show slow instabilities before the large dislocations of major earthquake.—Slow premonitory fault slip or fault-zone weakening precedes some, if not all, major earthquakes by a few hours or days. This feature has been directly observed in laboratory experiments on small rock samples and directly and indirectly in the field. If this phenomenon is characteristic of faults about to break, it may provide the key to short-term earthquake prediction at a specific locality on an active fault. Associated precursory Earth strain and tilt near the fault zone, minute displacement across the fault zone, and possibly geochemical, hydrologic, and magnetic variations may be observable before the fault breaks in a major earthquake.

Earthquake sequence characteristics repeat at the same location.—Earthquake sequences that occur decades apart at a given location have demonstrated nearly identical features. In a given region, geologic factors controlling magnitude, numbers of foreshocks and aftershocks, and earthquake intervals in time and space appear to be stable. This observation led the Geological Survey to issue an Earthquake Hazard Watch two days before a magnitude 6.0 earthquake near Mammoth Lakes, California, in May 1981.

Operating instrumentation networks.—Dense instrumentation networks for research purposes have been established in central and southern California, Utah, Missouri, and other locations.

Development of standardized data recording and computing facilities.—Capability for processing standardized seismic data at regional centers has been developed in cooperation with six universities. Data that are recorded and processed in standard ways can be shared more effectively between investigators. Results can be verified and data analysis techniques can be tested under a wide range of conditions and assumptions without error being introduced in the recording and processing phases of the analysis.

Current emphases

The current emphases in earthquake prediction research include:

Studies of several types of earthquake precursors: abnormal seismicity patterns, geodetic strain accumulations, water well fluctuations, geochemical, electrical, and magnetic field variations, and animal behavior.

Experiments in boreholes to determine the physical properties and conditions in active fault zones at depths down to about 1-2 kilometers.

Deployment of cooperative networks of instrumentation for earthquake prediction in highly seismic foreign areas, including: Turkey, the New Hebrides, the People's Republic of China, and the Caribbean. These data will accelerate our learning process and expand our information base.

Integrated, intensive instrumentation and field work along the San Andreas fault system in California where moderate earthquakes are expected within the next few years and large earthquakes are expected within the next few decades.

EARTHQUAKE DATA AND INFORMATION ELEMENT

The primary goal of this program element is to collect, analyze, and disseminate information on the occurrence and effects of earthquakes to the public, to the research community, and to those involved in earthquake mitigation efforts. One of the ongoing activities is to maintain and improve global and national networks of seismograph stations to provide a dependable data resource for fundamental studies in observational seismology.

Accomplishments

The accomplishments include:

Data on worldwide seismicity.—During 1980, data and information on about 7000 of the largest earthquakes occurring worldwide were provided by the National Earthquake Information Service (NEIS). These earthquakes are estimated to have caused more than 8500 deaths; the two most destructive being the October 10, 1980, Algerian earthquake and the November 20, 1980, Italian earthquake. Thirteen of these earthquakes had magnitudes between 7.0 and 7.9; one had a magnitude of 8.0. The largest earthquake affecting the United States was magnitude of 7.4 and took place on November 8, 1980, offshore California near Eureka. The July 27, 1980, Kentucky earthquake (magnitude 5.2) was felt in 14 states and Canada and served to remind of the earthquake threat in the eastern United States. These data were provided to scientists, government officials at all levels, and the public through routine publication and well established data dissemination procedures.

Current emphases

The current emphases include:

Continuation of the activities of NEIS to rapidly locate and evaluate the largest earthquakes happening throughout the world and to disseminate related data and information.

Support of the operation seismograph networks in the United States and worldwide to provide data on earthquakes.

Publication of seismicity maps for individual States. Maps are now complete and have been published for every State east of the Mississippi River, plus Missouri, Arkansas, and Louisiana.

INDUCED SEISMICITY ELEMENT

The goal of this program element is to determine how reservoirs and other activities of man cause earthquakes and what steps can be taken to mitigate this hazard.

Accomplishments

The principal accomplishments include:

A major experiment in South Carolina.—The filling of Monticello Reservoir in South Carolina in late 1977 induced a large number of small shallow earthquakes. Subsequently, two 1 kilometer deep boreholes were drilled into the earthquake cluster and used to measure stress and fluid pressure. This experiment demonstrated that a hydrologic connection exists between the fluids in the reservoir and those at depth and has improved the understanding of the cause of the induced seismicity in this reservoir.

Installation of an array of seismometers at Toktogul Reservoir, USSR.—This activity is a cooperative study of induced seismicity in an area of high seismicity. This study is providing unique data because a reservoir is being filled in a region with many earthquakes. This filling has caused a dramatic increase in seismicity in the vicinity of the dam.

Worldwide study of reservoirs.—A positive correlation between induced seismicity and water depth or rate of filling has been established for reservoirs throughout the world.

Current emphases

The current emphases include:

Continuation of investigations at Oroville reservoir in California. The goal is to determine if there is a physical relationship between the reservoir, the magnitude 5.7 earthquake that occurred in 1975, and the continuing seismic activity in the area.

Continuation of the development of a physical model to explain induced seismicity at the Monticello reservoir. The model will be based on measurements obtained in the two boreholes. Present data suggest that the earthquake activity takes place on extremely shallow joints and fractures within several hundred meters of the surface. The earthquakes appear to be induced by the subsurface change in fluid pressure resulting from impoundment of the water. These parameters appear to control the size of the maximum earthquake associated with a reservoir.

EARTHQUAKE HAZARDS WARNING AND INFORMATION DISSEMINATION ELEMENT

The goal of this program element is to transmit warnings about earthquake hazards as well as technical data and information to State and local officials.

Accomplishments

The primary accomplishments in this program element include the following:

Warning in May 1979 about the potential for a large earthquake in the Yakataga region of Alaska.—This warning was based on the seismic "gap" theory developed in the prediction program element.

Warning of earthquake hazard in eastern California.—On May 25, 1980, two earthquakes of magnitude approximately 6.0 occurred in the vicinity of Mammoth Lakes, California. Because earthquakes in this region had previously occurred in swarms, a Hazard Watch was issued to the Governors of California and Nevada on May 25, 1980. On May 27, 1980, a third earthquake of magnitude 6.0 occurred in the region.

Warning in July 1980 about the potential for a large earthquake in southern California.—In 1976, we expressed to the State of California our increased concern over the possibility of a large earthquake in southern California. This concern was based on small fluctuations in elevation in southern California between 1960 and 1974. Under current warning procedures this advisory would have been considered a "Hazard Watch." Last July we reviewed this warning and determined that it should remain in effect due to recent increases in seismicity and crustal strain variations. We so advised the State.

Conference on earthquake prediction information.—In January 1980, a 3-day conference on earthquake prediction information was sponsored by the Geological Survey, Federal Emergency Management Agency, California Division of Mines and Geology, California Office of Emergency Services, California Seismic Safety Commission, and City of Los Angeles. The conference brought together more than 100 government officials, scientists, engineers, social scientists, and civic leaders to identify constructive responses that could be taken through broad cooperative participation before and after an actual prediction of an earthquake. The conference proceedings were published and widely distributed.

Earthquake Prediction Evaluation Council.—A national council composed of 6 Government and 6 non-Government scientists was formed in August 1979. This Council advises the Director of the Geological Survey who is responsible for issuing a prediction or other information about the potential for the occurrence of future significant earthquakes. The council met last in January 1981 to evaluate a prediction at the request of the Government of Peru.

Communication linkages with States.—Points of contact have been established with every State and a number of meetings have been convened to work out procedures pertaining to warnings.

Current emphases

The current emphases include:

Continuation of research activities to define the potential for a large earthquake in California.

Convening conferences and workshops to improve the cooperative interaction of Federal, State, local, and private elements. The two most recent conferences dealt with the themes of "Evaluation of regional seismic hazards and risk" and "Earthquake hazards in the Puget Sound, Washington, area." A conference on the theme, "Responding to a destructive earthquake in the eastern United States," is planned for this year.

MANAGEMENT AND APPLICATION STRATEGIES

Below we discuss certain aspects of the management of our efforts under the National program and of the dissemination and implementation of our results.

Within the Geological Survey, the resposibility for carrying out the Earthquake Hazards Reduction Program is assigned to the Office of Earthquake Studies. This Office manages the program and conducts research and investigations using its staff of approximately 250 full-time scientists, engineers, and support personnel. This Office also supports closely coordinated contract work with universities and industry using about one-quarter of our total program resources. This strategy has succeeded in (1) greatly augmenting our capability without increasing our personnel roles, (2) identifying and improving local expertise in almost every region of the Nation, and (3) establishing "good neighbor" partnerships between Federal, State, local, and private elements of the Nation.

Planning for the execution of our role in the National Earthquake Hazards Reduction Program began in 1977 when the Geological Survey anticipated the need for a plan to guide non-Survey participants, to create a draft research plan. Its purpose was (1) to define short- and long-term research objectives, (2) to identify strategies for achieving optimum research results, (3) to provide a continuous feedback mechanisms for integrating results of research into the plan, and (4) to give Survey management and others a tool for evaluating and deciding on the options for future research. This plan has evolved into the "five-year plan" that is currently used by the Office of Earthquake Studies to manage its internal and external research. It contains clear objectives and milestones. It is a "dynamic" working document that is updated and refined every year in terms of new knowledge, actual accomplishments, national needs, and available resources.

The application or implementation of research results—in many cases at least as difficult as the research itself—is of major concern to us. Today, some 3½ years after the inception of the Earthquake Hazards Reduction Program, considerable progress has been made. Scientists and engineers throughout the Nation know much more about earthquake hazards and are more able to define the risk to people and property than they were in 1977. Many planners and decisionmakers now operate in an urban environment where public policy is much more favorable toward earthquake hazard mitigation than in 1977. Some examples of the improving record of utilization include:

Engineers have learned much more about the relationship between strong ground shaking and earthquake damage, and are designing buildings to resist predicted levels of ground motion.

Building codes in California and elsewhere are being revised to incorporate new knowledge and new practices to reduce earthquake damage.

Published maps of hazard-prone areas have increased community awareness of earthquake hazards, and have led planners and officials to adopt effective loss-reduction actions.

The Western States Seismic Safety Policy Council, formed by 10 Western States in 1979, meets annually to discuss local and regional strategies for earthquake hazard mitigation.

Two States, California and Utah, have active seismic safety councils that meet regularly to consider earthquake hazard issues.

Los Angeles created a task force in 1976 to plan a response to a prediction of an earthquake in the Los Angeles metropolitan area. Its consensus report, published in October 1978, provided a framework for this implementation activity.

Federal, State, and local government agencies in southern California began an earthquake preparedness project in 1980. Its goal is to accelerate preparedness at all levels for a catastrophic earthquake. The planning area covers the metropolitan portions of Los Angeles, San Bernardino, Riverside, Orange, and Ventura Counties. Planning includes family, neighborhood, institutional, industrial, financial, local, county, State, and Federal jurisdictions.

We continue to seek and to participate in activities to stimulate and accelerate application of our research. These efforts are carried out through:

Active participation in the Interagency Committee on Seismic Safety in Construction to improve building practices in the Federal sector.

Active participation in the development of new building codes such as proposed by the Applied Technology Council.

Planning jointly with State surveys and other State agencies methods and strategies for application of findings to disaster preparedness efforts.

Providing liaision and advisory services; for example, one of our scientists attends meetings of the Utah Seismic Safety Advisory Council and provides resources and technical assistance. Similar assisstance is given to the Association of Bay Area Governments.

Co-sponsoring and providing lecturers for FEMA Summer Institutes on Multiprotection Design which are attended by educators from many institutions.

Working through earthquake Engineering Research Institute to develop regional siminars on topics in earthquake engineering and related subjects. These seminars provide an opportunity for practicing design professionals, building officials, and policymakers to learn about the latest technical and scientific results in earthquake engineering.

Dissemination of research results through scientific and technical journals and Government publications. In 1980, our staff published about 200 papers and reports on their research and investigations related to the earthquake problem.

Publication and dissemination of periodic earthquake information summaries and a bi-monthly pamphlet, "Earthquake Information Bulletin", written for the lay reader.

In closing, we believe that our program is well defined, well balanced, well managed, and well on the road to reducing earthquake hazards in the United States. Much has been accomplished in what we believe can be described as a good start; much remains to be done. For these reasons, we recommend that the National Earthquake Hazards Reduction Program, and the Geological Survey's participation in it, be reauthorized for a period of 3 years. We believe an evaluation of the program at the end of that period will show significant progress and give an opportunity to change program balance or direction if required.

[The following information was subsequently received for the record:]

QUESTIONS OF THE COMMITTEE AND THE ANSWERS THERETO

Question 1. Has the USGS updated its computer systems where required?

Answer. We shall restrict our comments to the computer facilities used in the Earthquake Hazards Reduction Program. This program makes use of a MULTICS system that acts as the multi-purpose mainframe for USGS scientists in Menlo Park, California, and Denver, Colorado. The Earthquake Program has, in the past five years, purchased and maintained PDP 11/34-11/70 mini-computer systems at six locations where there is a demand for digital recording and interactive analysis of geophysical data. Software and data are exchanged between these six locations.

Recently the computing capacity of earthquake research centers in Menlo Park and Golden, Colorado, has been increased by the acquisition of intermediate-sized computers (VAX).

Question 2. Does the USGS have adequate travel funds to maintain contacts with foreign scientific developments.

Answer. Yes, funds are adequate; however, authorization for foreign travel is held at the Secretarial level within the Department of the Interior.

Senator SCHMITT. Our next witness is Dr. Jack Sanderson, Assistant Director for Engineering at the National Science Foundation. I understand you'll be accompanied by Dr. Robin Brett.

We have a statement here from Senator Cranston which will be included without objection in our record.

[The statement follows:]

STATEMENT OF HON. ALAN CRANSTON, U.S. SENATOR FROM CALIFORNIA

Mr. Chairman, thank you for the opportunity to comment on extending the authorization for the National Earthquake Hazards Reduction Act. As author of the Earthquake Disaster Mitigation Act, which formed the basis for the legislation you examine today, I am deeply appreciative of the priority this Subcommittee has given the extensions of our federal effort in earthquake prediction and hazard reduction research.

When we began this historic legislative effort in 1977, it was with the clear recognition that nearly every state in the nation faces some degree of risk from future earthquakes. Some 70 million people live in the 39 states that are wholly or in part in areas that risk high to moderate earthquake damage. The United States has suffered major earthquakes in South Carolina, Missouri, Massachusetts, Montana, Washington, California, and Alaska. The Pacific Coast states are historically vulnerable, especially Alaska and California, and the threat of major losses of human life has increased as our population becomes concentrated in major cities and along our coastal regions and where major construction has occurred on landfill and other unstable soils.

It was this national pattern of earthquake hazards, with concentrated manifestations in the Pacific states, that led us to make earthquake prediction and reduction a national policy priority. Under the National Earthquake Hazards Reduction Act as it now operates, the Federal Emergency Management Agency (FEMA) is the lead agency, carrying out the program begun under the mandate of the Congress.

Last year in testimony to the Subcommittee, I pointed out that our federal efforts have brought us to a relatively strong position in the areas of seismological and geological reserach, that our research in earthquake-related engineering is good, and that our applied research needs strengthening. I also indicated, Mr. Chairman, that we needed to better translate our research findings into a sound program for public action. That is still true today. After all, the entire thrust of this program is to save lives.

The urgency of this challenge was brought home to us in the past few months when we learned the details of an earthquake preparedness review carried out in California under auspices of the National Security Council, the U.S. Geological Survey, and the Federal Emergency Management Agency. You will hear testimony today by experts familiar with that study and its implication. In brief, that review concluded that a major earthquake in California is inevitable, with the overall possibility in excess of fifty percent in the next three decades. For the most probable catastrophic earthquake—a Richter magnitude 8-plus similar to the 1857 Ft. Tejon quake along the San Andreas fault—damage is estimated to be about $15 billion, with fatalities ranging from 3,000 to 13,000 depending upon the time of day. Although a less likely prospect, a magnitude 7.5 earthquake on the Newport-Inglewood fault in the immediate Los Angeles area would bring damage estimated at about $70 billion with fatalities between 4,000 and 23,000, again depending upon the time of day.

We also learned from this review, Mr. Chairman, that our federal-state preparedness was deficient, that our response in the event of a major earthquake would be inadequate and slow, and that the public was largely unprepared for effective survival in such an emergency.

What has happened in the months and weeks following that report, however, is a tribute to the legislative effort on review here today. There is now being carried out in California, under the leadership of Governor Brown, one of the most promising state and federal efforts in disaster preparedness this country has seen. With the help of FEMA, the earthquake response plan for the San Francisco Bay area has been joined by a similar plan for Southern California. The State is proposing the addition of over $4.5 million for the 1981–82 budget to increase the State's readiness to respond to a major earthquake. The program will be coordinated with the federal government and local agencies, and a major component will be the involvement of the private sector. This comprehensive effort is intended to increase the State's readiness, through clarification of authority and command, public education and volunteer training and identification of private and public resources for response and recovery.

As Senator from California, and as author of the legislation you review here today, I wholeheartedly support these actions. I am especially mindful of the role played by the Federal Emergency Management Agency in the carrying out of this cooperative effort. What we are seeing here is not a traditional federal agency response, in which strict directives are mandated by an agency, but a response in which the federal government makes it resources, knowledge, and expertise available to meet the specific needs of the region and the units of government to be served. To my mind, that promises the results we had in mind when we enacted this vital legislation.

Mr. Chairman, our relatively modest federal effort in earthquake prediction and hazard reduction has come up with some answers to earthquake-related responses that are desperately needed by the people who can make use of them. I feel strongly that the reauthorization of the earthquake legislation before you is not only critical in terms of continuing our basic and applied research, but is absolutely essential to saving lives and mitigating economic disaster. We are at a critical crossroad in this effort, and we need the time and financial support embodied in extension of the National Earthquake Hazards Reduction Act.

Senator SCHMITT. I see that either Dr. Brett has been cloned, or you have two other colleagues with you. Why don't you introduce them?

STATEMENT OF DR. JACK SANDERSON, ASSISTANT DIRECTOR FOR ENGINEERING, NATIONAL SCIENCE FOUNDATION, ACCOMPANIED BY DR. ROBIN BRETT, DR. CHARLES BABCOCK, AND DR. LEONARD JOHNSON

Dr. SANDERSON. Senator, we do have a couple of other people who are directly responsible for the programs.

First, let me say it is a real pleasure to be in this hearing today. With the increasing responsibility which this committee has for science and engineering at the National Science Foundation we look forward to a number of such hearings on the various aspects of science and engineering that are important to the Nation.

Both Dr. Brett and myself have prepared statements for the record. We have, in addition, each brought a colleague who is directly responsible for one of the programs. Accompanying me, on my right, is Dr. Babcock, who is the Section Head responsible for the earthquake hazards mitigation program in the Engineering Directorate. This is a focused program, aimed specifically at a number of key areas where knowledge is lacking to move successfully forward to full implementation of earthquake hazard mitigation.

Before I proceed with a few remarks, I think I would like to turn to Dr. Brett, let him introduce his colleague and make whatever remarks he'd like to.

Dr. BRETT. Would you like me to give my brief remarks first?

Dr. SANDERSON. Please.

Dr. BRETT. Mr. Chairman, I am pleased to be here to discuss the fundamental research of the geophysics program of the Division of Earth Sciences as it relates to the earthquake hazards reduction program. I realize, sir, you've had trouble with my accent for some 20 years now. I don't know what the solution is to that.

Senator SCHMITT. Slowly and distinctly.

Dr. BRETT. I request that the detailed statement I prepared be placed in the record, and I limit myself to a few short remarks. As you may be aware, I am not a seismologist, so therefore I have Dr. Leonard Johnson, program director for the geophysics program, to answer questions that may be of a seismological bent. The NSF program on fundamental earthquake studies comprises detailed studies and measurements directed toward the development of a thorough understanding of the natural phenomena involved in an earthquake.

The primary role is to establish the understanding and the scientific base of knowledge necessary for possible prediction of earthquakes and destructive ground motion. We believe that a solid, independent program of fundamental study will provide a framework on which more empirical programs of earthquake prediction can be based. Such a framework will help assure that an empirical program is scientifically sound and flexible and will provide direction for the best use of resources and, of course, will provide a reservoir of imaginative ideas, new experiments and basic theory that will be required if a particular empirical approach proves inadequate.

The fundamental earthquake studies program in the Earth Sciences Division can be defined in terms of two broad categories, plate tectonics and the earthquake process itself. The concept of plate tectonics has provided the conceptual basis for earthquakes and many other geophysical phenomena. And to repeat the answer to a question which I got recently, is a very satisfactory concept.

The earthquake process itself is less well understand, and is the subject of much attention. The plate tectonics concept envisages the Earth's surface to be composed of a discrete number of large plates moving relative to each other. The distribution of most of the world's earthquakes and their scientific radiation patterns may be used to define these plates. One of the ultimate objectives in earthquake studies is to understand how stress is accumulated, distributed and released along the boundaries of these moving plates. Such studies involve several disciplines and must be conducted on a global basis, both on land and sea.

Thus the research involved is not only directed toward earthquake prediction, but provides an essential framework for the design of such a program and can, in principle, lead to a comprehensive theory of prediction. The prediction of earthquakes and of destructive ground motion depends on an overall understanding of the mechanical processes leading up to and producing an earthquake. These processes must therefore be understood for the high pressure conditions that exist in the lower crust and upper mantle.

Theoretical models of the earthquake process consistent with the above information are required. Experiments, mostly on small samples, have revealed important information about the mechanics of faulting and the changes in the properties of rocks as the stress is built up. The proper scaling of the laboratory results and the intrinsic dependence of the results on the geometry and other conditions of the experiments are still to be determined.

Other active research areas include the delineation and understanding of seismic gaps, research on changes in radon content of ground water, studies of premonitory clustering of small earthquakes prior to a major earthquake, seismic reflection profiling across major fault zones, studies of slow, unfelt earthquakes as potential predictors, and studies of intraplate earthquakes, like those in New Madrid and the Wasatch fault system.

Funding for the program in the AAEO Directorate followed option B of the guidelines set by the Newmark-Steever report throughout the duration of those guidelines. This year we're funding the program at $7 million, a 6-percent increase over fiscal year 1980, the last year covered by the Newmark-Steever guidelines. In fiscal 1982, we're requesting $7.3 million, a 4-percent increase over fiscal 1981.

It is not realistic to attempt to predict the outcome of a fundamental research program in terms of technical milestones. I think from your own experience, you're very well aware of that. You just can't tell where, when you follow your nose, you're going to end up. I think we can be very confident that excellent results will continue to come out over the next 10 to 15 years. Nevertheless, we can reasonably predict that basic research effort focused on projects with a strong potential for application to the earthquake prediction and hazard reduction program will result in a more comprehensive understanding of the earthquake process. Progress in such basic understanding can be expected to increase the efficiency, as well as the reliability of earthquake prediction.

I and my colleague, Dr. Johnson, will be happy to answer any questions that you may have, and I pass over to Dr. Sanderson. Thank you.

[The statement follows:]

STATEMENT OF DR. ROBIN BRETT, DIRECTOR, DIVISION OF EARTH SCIENCES, NATIONAL SCIENCE FOUNDATION

Mr. Chairman and Members of the Committee, I am pleased to be here to discuss the fundamental research of the Geophysics Program of the Division of Earth Sciences as it relates to the Earthquake Hazards Reduction Program. The Geophysics Program covers the sub-fields of seismology, gravity, geodesy, magnetism, earth currents, heat flow, and the behavior of natural materials at high pressures. Seismology is perhaps the most important area of geophysics in that it is the primary method of studying the structure and physical properties of the earth's interior and is a primary method of outlining the plates making up the earth's lithosphere and of studying the detailed structure of the earth's interior. As such, seismology, and other earthquake related areas have been of long term interest to the Geophysics Program and have in fact constituted more than half of its program since its inception some 20 years ago. The importance of the Earthquake Hazards Reduction Program to the Geophysics Program is in giving a focus and stressing importance of the research to the concerned scientific community and ensuring good coordination, both in that community and among the Government agencies. This NSF program on fundamental earthquake studies consists of in-depth studies and measurements directed at understanding the natural phenomena involved in an earthquake. The primary goal is to establish a fundamental base of knowledge necessary for the potential prediction of earthquakes and destructive ground motion. We believe that an independent program of fundamental studies will provide the basic scientific framework on which more empirical programs of earthquake prediction can be based. Such a framework will help assure that an empirical program is scientifically sound and flexible, will provide direction for the optimal use of resources and, of course, will provide a reservoir of imaginative ideas, new experiments and basic theory if a particular empirical approach proves inadequate.

The program of fundamental earthquake studies at NSF can be defined in terms of two broad categories: plate tectonics and the earthquake process. The plate tectonics concept envisions the earth's surface to be composed of a discrete number of large plates moving relative to each other. The distribution of most of the world's earthquakes and their sesimic radiation patterns may be used to define these plates. One of the ultimate objectives in earthquake studies is to understand how stress is accumulated, distributed, and released along the boundaries of these moving plates. Such studies involve several disciplines and must be conducted on a global basis both on land and at sea. Thus the research involved is not only directed towards earthquake prediction, but provides an essential framework for the design of such a program, and can in principle lead to a comprehensive theory of prediction.

Despite the simplicity of the plate tectonics concept, large and destructive intraplate earthquakes (e.g. New Madrid, Missouri in 1811 and 1812, Boston Massachusetts in 1755, and Charleston, South Carolina in 1886), continue to complicate the model. Such earthquakes appear to have causes different from those along the San Andreas fault system in California and may well prove to be most difficult to forecast. Ideally, measurements of intraplate stresses and strains on a plate-wide and worldwide basis are required, together with more local studies on the relationship of seismicity to buried structure in known seismic regions, if we are to understand the reasons for such large within-plate earthquakes.

The prediction of earthquakes and of destructive ground motion depends on a thorough understanding of the mechanical processes leading up to and constituting an earthquake. These processes must therefore be understood for the high pressure conditions that exist in the lower crust and upper mantle. Theoretical models of the earthquake process consistent with the above information are required. Both pre-earthquake phenomena and the gound motion resulting from the earthquake are intimately related in many cases to faulting or rupture at depth. We do not yet know what physical properties are the most critical or the nature of the instability that results in an earthquake. The failure criteria and the role of "stick-slip" and creep in the earthquake process must be understood in order to calculate fault propagation in ambient stress fields. In addition, the properties of the materials involved and the geological setting of the regions affect the amount of energy released and the characteristics of the generated motion. In summary, to solve the problems of earthquake prediction, a blend of theoretical, laboratory and field studies is essential.

There have been significant recent achievements in all of the areas I have just mentioned. I will discuss just a few. We have a beginning understanding of the dynamic process of faulting—how a fault rupture nucleates, spreads, and finally stops, and we can model the effects seen in seismograms from each of these three stages in the faulting process. This new knowledge is the product of a combination of field, laboratory, and theoretical studies.

A picture of very large earthquakes that has emerged as probably being quite general is that they are multiple events. Rupture begins on a long fault, pauses momentarily, presumably on reaching a strong point on the fault, then proceeds, perhaps with several other jerks, before the total rupture is complete.

Understanding of rock mechanics prior to an earthquake is essential to a rational approach to earthquake prediction. Experiments, mostly on small samples, have revealed important information about the mechanics of faulting and the changes in the properties of rocks as the stresses build up to cause failure. The proper scaling of these laboratory results to the field and the intrinsic dependence of the results on the geometry and other conditions of the experiments are still to be determined.

There has been a significant amont of recent research dealing with groundwater radon content as an earthquake precursor. Many rocks, particularly granites, contain trace amounts of radioactive elements. As these elements decay, they give off harmless quantities of radon, a radioactive gas with a short half-life. Because of its radioactive nature and its solubility in water, radon can be detected in minute quantities in ground water. Also, because of its inertness, its concentration in ground water usually independent of fundamental hydrological characteristics-water composition, mineralization, and temperature. Rather, its fluctuations depend to a large extent on the alteration of the geometry of mineral grains in the rock. According to one possible mechanism for an earthquake occurrence, when regional stress increases, there may be an increase in either the surface area of rocks due to cracking or in the flow rate of pore fluids as they are forced out of interstitial spaces. Both of these processes will enhance the transport of radon from its original enclosures in the rock mass into the groundwater.

Increases have been observed prior to earthquakes in the quantity of radon in the ground water of wells in Southern California, Japan, China and the Soviet Union. Although our understanding of the whole mechanism of radon emission remains unclear, the observed precursory changes must somehow reflect the deformation or damage, or both, to the artesian layer caused by the action of stress release or accumulation. Much work must still be done before we understand the detailed mechanism of stress-induced radon emission and radon transport.

It has recently been hypothesized that there may be "slow" unfelt earthquakes that precede the more usual ones with which we are familiar. If so, the observation of "slow" earthquakes would provide a predictor. Most seismographs will not respond to such low frequencies. However, the network of 16 worldwide, ultra-long period instruments supported by NSF and operated by scientists at the University of California, San Diego, is ideal for the recording of "slow" earthquakes. A search for their existence is currently being conducted in at least three other university research laboratories, using data from this network.

Another area of recent activity related to the earthquake process is the discovery that a number of major earthquakes have been preceded by a premonitory clustering of small earthquake events in their epicentral regions. Premonitory clustering is more difficult to detect than typical foreshock activity because it occurs more diffusely in space and time and because it tends to be masked by the random background of continuing low-level seismicity. However, by application of statistical methods, it can be identified and distinguished from the statistically random clustering that occurs as part of the normal seismicity background. Clustering in time seems to be correlated with clustering in space and, as already noted, with the subsequent occurrence of larger earthquakes. These conclusions are now being further pursued and tested.

Fundamental studies of earthquakes and the theory of plate tectonics are intimately related. Most of the world's earthquakes occur along well defined belts that coincide with plate boundaries. The energy that is released in large shallow shocks builds up slowly along fault zones at plate boundaries. This stress results from the relative movement of the plates, which, when averaged over thousands of years, varies from 2 to 12 centimeters per year. Friction along the plate boundary, however, prevents continous and smooth movement. Parts of a plate boundary that are well defined by geological evidence and that have not experienced large earthquakes for tens to hundreds of years are likely to be sites of future large shocks. These areas have received a special name; they are called "seismic gaps". This concept is proving to be a valuable aid in pinpointing the sites of future large shocks. Several large earthquakes have occurred in recent years in previously identified seismic gaps, most notably the 1978 earthquake in Oaxaca, Mexico and the 1979 earthquake in Alaska in the so called Yakataga gap.

A considerable amount of effort is being put into studying the plate boundaries of the world to determine historical repeat times of earthquakes so as to be able to identify seismic gaps. Some areas, such as those near the coasts of Mexico, Central America and southern Alaska are characterized by repeat times of less than 100 years. Some of these areas have a high potential for being sites of future great shocks. While the gap concept itself cannot be used to predict the time of occurrence of a future shock with much precision, once the area itself is identified more detailed local monitoring of that area may provide data on other precursory effects to make a more precise prediction.

We know that a spherically symmetrical seismic velocity model is only a crude approximation of the real Earth, in terms of the high reliability of modern data. Recent studies of the crust and upper mantle, interpreted in terms of plate tectonics, show the typical values and the scale of lateral heterogeneities. Because of the fundamental importance of lateral variations in structure to our understanding of geodynamic processes, as well as improved accuracy in locating earthquakes, a variety of approaches are being taken to map these details. Seismic reflection profiles now probe fairly deep into the crust and upper mantle and have produced spectacular results in some cases.

The Consortium for Continental Reflection Profiling (COCORP) project supported in the Earth Sciences Division is providing several types of information of importance to the understanding of earthquakes and to the reduction of the earthquake hazard. The most fundamental kind of relevant information is simply the structure of the crust as it bears on the earthquake problem. For example, COCORP recently discovered a mojor low angle thrust with crystalline basement rocks of the southern Appalachians shoved over shallow dipping Paleozoic sediments at depths beneath the crystalline rocks of the southern Appalachians. This discovery puts a new light on the study of earthquake activity near Charleston, South Carolina, and on earthquake activity elsewhere in the Appalachians.

COCORP has already demonstrated the ability to detect and trace faults deep in the crust. In Wyoming the Wind River Thrust was followed to depths of 25 km. In California, the brittle part of the San Andreas fault zone was followed to 12 km with an apparently ductile zone occurring beneath. Such improved knowledge of deep structure offers the possibility of associating well-located earthquakes with particular faults whose tectonic significance is well understood.

Significant governmental programs in the area of earthquake prediction and seismic hazard mitigation exist in Japan, the Soviet Union, and the Peoples' Republic of China. There continues to be close liaison and cooperation in the area of fundamental studies between the United States program and the foreign programs I have just mentioned. In particular, there has been recent activity under the protocol for cooperative earthquake studies between the NSF, the USGS, and the State Seismological of the People's Republic of China, which was signed in Peking in January 1980.

Scientists from the two countries hope to perfect the measurement of gravity changes as as additional method of prediction. The scientists will work in a 50,000 sqare-mile area around Peking. The region is one of the world's most seismically active and offers conditions for gravity research more favorable than those in the United States. There have been many destructive earthquakes in the region, with substantial vertical motions due to crustal deformation. Two of the most severe occurred in 1975 in Haicheng and in 1976 in Tangshan, 300 and 90 miles east of Peking, respectively. Chinese scientist measured gravity changes before and after both quakes, but they believe the precision of the observations was not great enough to establish a definite relationship to the quakes.

The Chinese and American researchers will set up and maintain eight gravimeters at 15 semi-permanent stations over the next few years. The instruments will make continuous recordings, unlike previous gravity surveys in which only single measurements were made. In addition, three portable gravimeters will be moved periodically among some 100 other locations to monitor local gravity variations.

Another project initiated under this protocol during the past year is the installation of an ultra-long period seismometer at a station in Kunming in southwestern China. This instrument is part of a worldwide network of such identical instruments for studying very low frequency seismic phenomena such as the so-called "slow" unfelt earthquakes previously mentioned.

Funding for the program in the AAEO Directorate followed Option B of the guidelines set by the Newmark-Stever report throughout the duration of those guidelines. This year (FY 1981) we except to fund the program at $7.0M, a 6 percent increase over FY 1980, the last year covered by the Newmark-Stever guidelines. The funding requested for FY 1982 is $7.3M, a 4 percent increase over FY 1981.

It is not realistic to attempt to predict the outcome of a fundamental research program in terms of "technical milestones." Nevertheless, we can reasonably predict that a basic research effort, focused on projects with a strong potential for application to the earthquake prediction and hazard reduction program, will result in a more comprehensive understanding of the earthquake process. Progress in such basic understanding can be expected to increase the efficiency as well as the reliability of earthquake prediction. Some present approaches to the problem, although promising, may conceivably fail. This is good reason to have a reservoir of imaginative ideas, new experiments, and basic theory that fundamental studies can generate.

Close coordination among the Geophysics Program, the earthquake prediction program of the USGS, and the earthquake research programs of other agencies is of great importance. This is attained by close personal contacts of Program personnel and by liaison membership on each other's Advisory Committees and Evaluation Committees.

I shall be happy to answer any questions you or members of the subcommittee may have.

Senator SCHMITT. Thank you. Dr. Sanderson?

Dr. SANDERSON. Thank you, Senator Schmitt. The National Science Foundation, as you're well aware, has been supporting research not only into the fundamental nature of the Earth sciences plate tectonics, but in the earthquake-related problems themselves, since the early 1960's. The support of research in the problem-focused areas has accelerated with the passage of Public Law 95-124, the Earthquake Hazards Reduction Act of 1977. Since that time, we have obligated about $70 million to support the objectives of that act.

The primary objectives of the research that we support are first to determine the nature of the strong ground motion itself from experimental data and models of what's going on in the Earth.

These models and data are necessary to be able to predict the strong ground forces which would be encountered at a particular site, where you might want to construct a building, a water supply, or other manmade object.

The second focus of our research is to develop an understanding of the dynamic response of manmade structures so that we can predict the damage that will be incurred, once the loading due to earthquake forces is known.

Finally, we have a program in social response to try and carry out social science-related research, to develop and understand some of the problems which stand in the way of effectively implementing what we currently know and ways to improve the delivery of services, both in preparing in advance for an earthquake, and in relieving the human and economic suffering that will exist after an earthquake has occurred.

The Foundation has successfully produced a number of significant achievements in this research program. I cite some of them in my written testimony, which is in the record. I think it's important to realize when we're talking about progress in earthquake research, that the first strong ground motion data that could be used for engineering purposes was not obtained until the 1940 El Centro earthquake. Because of the absence of strong ground motion instrumentation there was no useful information obtained during the 1964 earthquake in Alaska. However, very useful records were obtained during the San Fernando earthquake in 1971. In fact, on that occasion we got more data than we had obtained during the entire previous history of the United States.

The strong ground motion program which is supported by the National Science Foundation and carried out jointly with the U.S. Geological Survey represents a major source of experimental data in this direction. We have also been supporting analytical studies of earthquake source mechanisms, and we now are beginning to be able to duplicate, based on models using five parameters, the actual observed forces and ground motions that occurred at a specific site some distance from the potential earthquake fault. Both of these are important in enabling us to understand the forces which will occur when an earthquake releases its energy.

In addition, we've been supporting research on the design of earthquake resistant structures. Dr. Popov of the University of California in Berkeley has developed a new technique for eccentric bracing in a steel beam building. This has created a structure which is significantly more seismically resistant than with normal construction techniques. That type of construction has already been introduced into a number of the larger steel girder buildings which are being constructed in the State of California.

Looking ahead, we see a number of areas where there are significant opportunities for further research. The total area of lifelines is becoming of increasing concern to the research communities; problems of maintaining gas, water, electricity, other services which are important to the survival and recovery of a community.

Another area in which there is a planned increased emphasis, is the problem of dealing with existing hazardous buildings. The cost of retrofitting the housing stock of California using normal technologies is staggering. That is [illegible] obstacles to moving ahead and trying to do something to retrofit in order to improve seismic safety in areas such as Los Angeles. We're studying a number of techniques. One we're interested in is to actually excavate under a building and mount the building on rubber shock mounts. An experiment of this type is under way now, to see if this can be done economically and successfully with this technique, the building will be effectively decoupled from much of the earthquake force which is transmitted through the ground.

We have also been carrying out planning activities, jointly with FEMA, with the other agencies who are represented here today, and with other government agencies, such as the Department of the Defense, GSA, HUD, the Bureau of Standards, and the VA. In these we are looking at some of the research issues which need to be addressed. This work with the other Federal agencies, has been complemented by an external advisory committee which we have established for our earthquake hazards mitigation program, to provide us the best scientific, engineering, and technical advice we can get from the outside community. This advisory committee is a key factor in helping us evaluate the research opportunities which the program will address over the next few years.

We will be glad to answer any questions.

[The statement follows:]

STATEMENT OF DR. JACK SANDERSON, ASSISTANT DIRECTOR, ENGINEERING, NATIONAL SCIENCE FOUNDATION

Mr. Chairman and Members of the Subcommittee, today, I am happy to report to you on the current program and future plans for the Engineering Directorate's Earthquake Hazards Mitigation (EHM) research program.

The National Science Foundation has supported research on earthquake-related problems since the early 1960's. With the passage of the earthquake hazard reduction act in 1977, P.L. 95-124, our efforts have expanded and good results continue to be achieved. Since then we have obligated about 70 million dollars to support the objectives of that act.

The aim of the Earthquake Hazards Mitigation program is to support research which develops understanding of earthquake related phenomena in order to help reduce casualties, damage, and social and economic disruption from such events.

The primary objectives of this research are:

To determine the nature of strong ground shaking from experimental data and models and to develop analytical procedures to predict the spatial and temporal distribution of strong motion; to understand the dynamic behavior of soil and rock subjected to strong shaking; and to determine the nature of the interaction between structures and the supporting soil during earthquakes.

To develop procedures for dynamic analyses of proposed or existing construction under earthquake loadings; to develop an understanding of materials, structural components and designs for areas potentially subjected to damaging dynamic loads; to develop procedures for analysis and design of non-structural and architectural systems; and to study the influence of architecture and urban planning activities on earthquake vulnerability; and

To develop and evaluate measures which can be used to mitigate and respond to earthquake impacts, including emergency preparedness, land-use planning, building codes, insurance, and information and education.

The Earthquake Hazards Mitigation program is divided into three subelements, each with its own goals and objectives. These subelements are coordinated by the section head who is responsible for maintaining program balance and meeting program goals. The three subelements are Siting, Design, and Societal Response.

The Siting subelement supports research to establish physical relationships between energy released at the earthquake source and resulting seismic waves that propagate through geological strata and bodies of water. This research also deals with the interaction between earthquake-generated ground motion, water wave forces, and manmade structures, or other facilities. Specific objectives of this subelements are to:

Determine the propagation, spatial characteristics, and strength of seismic ground motions through use of strong-motion instrument arrays and through theroretical and experimental engineering seismology investigations;

Determine how damaging earthquake ground motions are modified by local geological and geotechnical conditions;

Develop seismic risk assessment procedures and apply these procedures in planning and engineering design;

Investigate the three-dimensional, nonlinear characteristics of soil response and soil-structure interaction for various soil conditions; and

Develop siting and planning capabilities for improved seismic safety for major structures and industrial facilities.

The FY 1982 budget request for the Siting subelement is $9,650,000.

The Design subelement supports research to improve the scientific and technological basis for understanding and predicting the behavior of a wide variety of structures and facilities which could be subjected to seismic forces. Some specific research objectives of this subelement are to:

Develop analytical and computer methods to understand the response of structures from initial damage to collapse;

Develop methods to understand and predict the response of nonstructural systems, architectural elements, and building contents from damage initiation to total failure;

Develop information on the behavior of actual structures and large-scale laboratory models to validate theories, establish scale relations, and formulate design concepts;

Study the behavior of low-rise structures to reduce potential damage from earthquakes;

Study the influence of architectural and urban planning considerations on the earthquake vulnerability of buildings and communities;

Stimulate research on innovative alteration methods for improving the safety and structural performance of existing structures and facilities; and

Transfer new research information into improved design practice.

The fiscal year 1982 budget request for the Design subelement is $7,720,000.

The Societal Response subelement seeks to enhance the understanding of the steps that society can make to reduce loss from earthquakes and other hazards. These include emergency preparedness, land-use planning, insurance, building standards, and relief and rehabilitation. Emphasis is also given to increasing knowledge of public information and education efforts so that needed information can be disseminated to appropriate user groups.

Specific objectives of this research are to:

Develop knowledge about the socioeconomic aspects of hazards mitigation;

Increase the base of knowledge about preparedness for earthquakes and other hazards;

Improve the understanding of disaster impacts and responses; and

Provide a basis for improving the information dissemination on hazards and its utilization by decisionmakers and the public.

The fiscal year 1982 budget request for the Societal Response subelement is $2,480,000.

Today I will review with you some of the activities and recent accomplishments of our program. I will consider the events prior to an earthquake, the earthquake itself, and events after the earthquake. By associating research projects with these various phases, I hope it will be easier to understand how the research we support is directed at mitigating the overall effects of earthquake hazards.

Prior to an earthquake attention is focused on the issues of preparedness. From an engineering standpoint, preparedness is measured by the quality of building codes, the degree of seismic safety of the existing building stock, the seismic safety of architectural and non-structural items, the seismic "hardness" of lifelines such as public utilities, highways, etc., the appropriateness of land use and the safety of critical facilities. All of these aspects change over a long period of time and are significantly influenced by technical, social, economic and political considerations. The implementation of an improvement in a seismic building code provides an interesting example. The basis for the code change could be, for example, increased understanding of how to strengthen existing buildings. This understanding would be the result of fundamental research, but this in itself would not be sufficient without demonstrating to practicing engineers that the proposed changes would indeed increase seismic safety at costs compatible with the degree of protection provided. Once the technical community supports the idea, the governmental arena becomes important. Further progress in providing increased seismic protectior nds upon public acceptance and confidence in the information provided by the technical community.

With respect to other technical advancements, these are often easier to put into effect. For example, a new eccentric steel bracing system for high-rise buildings which promises improved seismic performance and significant savings in materials and erection costs has resulted from research performed by Dr. Egor Popov at the University of California, Berkeley. The system incorporates diagonal bracing members between floors in an arrangement which increases the energy absorbing characteristics of the principal structural system. The energy absorbing capability of the bracing system results in a lessening of damage to the building during an earthquake. Dr. Popov's findings are already being incorporated in the construction of several major buildings in California.

Another important part of preparedness is the problem of supplying vital utilities to an earthquake damaged area. This has received increasing emphasis since the 1971 San Fernando earthquake. That earthquake alerted the technical community to the problems of increasing the seismic performance of lifelines such as water, energy, communication, and transportation. Subsequently, we have supported projects to develop the methodology for modeling and analysis. Using this knowledge base, risk and decision analysis has been applied to real systems. The research has resulted in design aids, guides and specifications to be utilized by engineers and policy making bodies.

A number of research projects have addressed institutional issues concerning preparedness. Findings from these studies are an important part of the data base being used by the Southern California Earthquake Preparedness Project, which is jointly funded by the California Seismic Safety Commission and the Federal Emergency Management Agency with local participation. This project is a prototype effort involving both the public and private sectors in planning for an earthquake prediction and for a major earthquake.

When the earthquake occurs, the preparedness phase of the earthquake cycle ends abruptly. The test of preparedness is over in less than a minute. Obviously, nothing useful can be done during this period to protect property and very little to protect life. The events that occur are extraordinarily complex. This complexity arises due to a poorly understood natural phenomenon interacting with the extremely diverse works of man. The largest part of our research is devoted to this phase so that we can better prepare for its inevitable but as yet unpredictable occurrence.

From an engineering point of view, we are most concerned with the behavior of the earth in the vicinity of a ruptured fault. Such research, commonly called the study of strong ground motion, receives about 20% of our research funds. We take two complementary approaches to the problem. The first is an experimental one where instruments, called accelerographs, are placed in sites where we expect large earthquakes to occur. Since these are, fortunately, somewhat rare in the United States, we pursue this type of research throughout the world. Our international activities in the strong ground motion program involve India, Taiwan, and, recently, the People's Republic of China. The research in Taiwan has already yielded significant results. Twenty-three instruments were triggered during an October 1980 earthquake. The concentric design of this array provided us with unique strong ground motion records.

I should point out that the first strong ground motion accelerogram useful for engineering purposes was not obtained until the 1940 El Centro (California) earthquake. Because of the absence of instrumentation, no records were obtained during the great 1964 Alaska earthquake. More useful records were obtained during the San Fernando (California) earthquake of 1971 than in the entire previous history of the United States. The Strong Ground Motion Program, which is funded by NSF and carried out by the United States Geological Survey, recently obtained important records during the 1979 El Centro Earthquake. These unique records, which contained one record from the same site as the 1940 record, were important additions to our strong ground motion data bank.

We support analytical studies of earthquake source mechanisms to complement the instrumentation program. This work, carried out by seismologists in a number of institutions, analyzes how strong ground motion is influenced by the source properties (such as fault slip, fault size and propagation rate) and local geology. Our objective is to obtain a better understanding of the experimental strong ground motion records and to predict the motion at a specific site that might be produced by a potential earthquake fault.

It only takes a few seconds for the rupturing fault to transmit energy to structures. The structures, whether buildings, dams, transmission lines, or nuclear power plants, will be subjected to seismic waves traveling as fast as five thousand miles per hour and lasting from a few seconds to a minute. The study of the response of these structures to the excitation utilizes a large part (about 50%) of our research funds. Again, both experimental and analytical work is pursued.

Virtually every area of engineering is involved in structural response research. Most of the research is done by investigators in civil and mechanical engineering but the program also supports researchers in metallurgy, mining, oceanography, mathematics and mechanics. This broad scope is due to the diversity of structures that are built in the vicinity of active faults.

Recently research in this area has been carried out at the University of California, Berkeley and at California Institute of Technology on the response of water tanks. In many earthquakes, the failure of these tanks has hampered fire-fighting efforts. Scale-model tests at Berkeley, full-scale vibration tests at Caltech, and analytical work at both schools have built a solid base of knowledge concerning this complicated fluid-structure interaction problem. This knowledge has led to simplified procedures which allow seismic design improvements to be incorporated into existing as well as new tanks.

After the earthquake, the recovery period begins. This can be divided into immediate and longer-term phases. In the early phase, the dominant consideration is to save lives, e.g., rescue trapped victims, provide prompt medical treatment, and supply food, shelter, and clothing to the population.

Our appreciation of problems that are likely to occur during major earthquakes has been increased due to studies of recent disasters. Researchers at the Univeristy of Denver, for example, are completing the most systematic study to date on search and rescue during emergency periods of disasters. A team at Battelle Memorial Institute has completed a comprehensive study of disaster evacuation. Also, the Mt. St. Helens eruption has enabled researchers to learn a number of lessons regarding emergency response and relief and rehabilitation efforts which decision-makers should find useful in preparing for future earthquakes and other disasters.

The recovery period is one that can be effectively used by the engineering community to improve the seismic performance of structures. From the standpoint of increasing our understanding, an earthquake is a gigantic full scale experiment. It is the proof of the pudding. The 1979 Imperial Valley, California earthquake offered such a unique opportunity since it occurred close to an instrumented building which failed. This building had been the subject of previous experimentation. The EHM program planned and coordinated research activities using the building as a focal point. Prior to its final demolition, many test samples were removed from the structure to determine if the building materials met the construction specifications. This information and that from building plans were used to construct mathematical models of the building. These models allow the analysis of the adequacy of the design procedures and the cost-effectiveness of new seismic provisions. The earthquake enabled researchers to validate their models because the building had been studied earlier.

Research on the longer post-disaster period demonstrates that while most individuals and communities eventually recover from earthquakes, they seldom use these experiences to increase their level of preparedness for future events. Only a few communities have used the post-earthquake context to improve building codes and land use planning. The trend in the recovery period is to restore the community to its pre-disaster state, which includes a return to the practices that failed to consider seismic safety measures. Research supported by this program is beginning to uncover the key factors which influence post-disaster mitigation and preparedness actions.

As I have tried to point out by using this time sequence of events, the EHM program is involved in all phases of the earthquake problem: i.e., the pre-disaster, immediate post-disaster, and recovery periods.

What lies ahead? Our future plans in this program include two objectives. The first is to maintain the fundamental base of research that is producing the necessary knowledge to understand better the earthquake process as it affects engineered structures; to improve the engineering knowledge necessary for the propper design, construction and maintenance of these structures; and to increase the understanding of the various aspects of hazard mitigation and disaster impact. The second objective is to develop new activities in high priority areas.

In order to achieve this objective, we have established procedures to identify high priority items and to formulate new program plans. For example, we have formed an advisory committee for the program with members from the engineering and scientific research community as well as from public organizations responsible for enhancing seismic safety. This is a working committee which has set up eight task groups to help in areas ranging from planning to program management. The committee has identified several high priority research topics.

Existing hazardous buildings is one such area that is receiving increased program attention. In Los Angeles alone, the number of buildings that do not meet any standards for earthquake resistance has been estimated at 8,000. The nonconforming buildings are those constructed prior to 1933 and still in use. Many such buildings can be found in almost every other community in California and elsewhere. The cost of reinforcing these buildings so that they would not collapse a strong earthquake is estimated in the billions of dollars.

We will also give more emphasis to research to expand our understanding of the factors that influence the adoption and implementation of such mitigation and preparedness measures as building codes, land use requirements, earthquake prediction, and public education; the costs, benefits and other consequences of adopting such measures; and their relative effectiveness.

We are also developing plans to improve the management of the national strong ground motion program, to facilitate information dissemination and technology implementation activities, and to assess the future needs for large-scale testing of structures.

Program planning is carried out in coordination with related research activities within the Foundation and with other Federal agencies. An example is research on existing hazardous buildings mentioned earlier. The following Government agencies participated in the program planning phase: Department of Defense, Federal Emergency Management Agency, General Services Administration, Department of Housing and Urban Development, National Bureau of Standards, Veterans Administration, National Endowment for the Arts, and the Department of Interior.

The Program Directors in the Earthquake Hazards Mitigation Program serve on a number of intergency committees. The interagency committees include the Interagency Committee on Seismic Safety in Construction, Seismic Interchange Group, Interagency Working Group for Earthquake Engineering Research Coordination, the Interagency Discussion Group on Architecture and Planning Research, and the Interagency Discussion Group on Disaster Mitigation. All of these activities ensure that the research program is closely coordinated with those of other Federal agencies.

Thank you Mr. Chairman for allowing me to discuss the activities of the Earthquake Hazards Mitigation Program as carried out by the Engineering Directorate. We are mkaing progress in providing the necessary knowledge base to reduce the hazards of constructing increasingly elaborate structures on an ever-shifting earth crust. We are enthusiastic about our work and I hope that I have been able to convey some of that enthusiasm to you.

I shall be happy to answer any questions you or members of the Subcommittee may have.

[The following information was subsequently received for the record:]

National Science Foundation,
Washington, D.C., April 23, 1981.

Hon. Bob Packwood,
Chairman, Committee on Commerce, Science, and Transportation,
U.S. Senate, Washington, D.C.

Dear Mr. Chairman: I am pleased to respond to your questions for the record from the April 6, 1981, hearing of the Subcommittee on Science, Technology and Space regarding the reauthorization of the Earthquake Hazards Reduction Act of 1977.

Question. Have you made requests to expand your program in areas of research opportunities?

Answer. The National Science Foundation submits to the Office of Management and Budget a Zero-Base Budget request which provides details on program activities at a number of budget levels. In addition, I have submitted, as part of the planning activities for the Earthquake Hazards Reduction Program, a multiple-year plan for NSF-sponsored research which includes identification of a number of new research opportunities and our best estimate regarding their priority. This latter material has been incorporated in the multiple-year Earthquake Hazards Reduction Plan prepared jointly by NSF, USGS, and others under the leadership of FEMA. In both the ZBB document and the long-range planning, requests were included to expand the program of Earthquake Hazards Research in NSF as part of NSF's proposed program level.

Question. How has OMB treated such requests?

Answer. The priority areas of expansion included in the requests are detailed on the attached list in priority order. They were viewed of lower priority within the constraints of the overall Federal budget and, thereofre, do not appear in the revised President's Budget to the Congress, March 1981.

I appreciate your interest in the Foundation's program on Earthquake Hazards Research and would welcome the opportunity to work with you or your staff in resolving any issues. Within the resources requested, I believe, the Foundation has a strong and viable program of research.

Sincerely,

JACK T. SANDERSON,
Assistant Director for Engineering.

Attachment.

DIVISION OF CIVIL AND ENVIRONMENTAL ENGINEERING EARTHQUAKE HAZARDS MITIGATION PROGRAM

Budget Requests to OMB not included in the President's Budget of March 1981:

$350,000—To improve the mathematical basis for analyzing nonlinear structural dynamic behavior and to fund additional research initiation grants to aid new researchers entering the earthquake hazard mitigation field.

$1,500,000—To undertake post-disaster audits of buildings and public facilities; to evaluate the effectiveness of financial policies in achieving reduction of hazards; to accelerate study of the methods used to evaluate the hazard potential of existing buildings; to develop methods of analysis of lifeline systems; to design and install strong motion instrument arrays to complement the one planned under the six priority sites in the world.

$300,000—To implement a mobile strong motion instrument array for aftershock measurmenets of a major U.S. earthquake.

Senator SCHMITT. Thank you, Doctor.

Dr. Sanderson, do you think that the longer term or gap-predictive techniques that the U.S. Geological Survey is developing and has developed, could be used by Federal, State, and local entities to plan their zoning criteria, relative to new construction in earthquake hazard zones?

Dr. SANDERSON. You're talking a matter of scale here, Senator. Certainly the gap-predicting capabilities give us a strong indication of where there are likely to be quakes of severe magnitude over some reasonable period of time. We then need to know from the fact that that fault will let go, the types of ground motion expected and what will occur at the specific block or specific area, and hence what type of construction we can allow in building. There are obviously some areas near a fault, where it would be hazardous to put any sizable construction activities. However, there are other areas where the value of the land is such that we're going to have construction on the site that's almost impossible to prevent. Then, we need to know what types of construction are allowable and what types of safety measures are going to be required in the process of construction.

A number of earthquake phenomena can take place at a very localized level, including the interaction between one building and the soil underneath it. Under the right conditions, the soil can liquefy, and the building can then sink into it. It's research on these types of problems that we are currently placing a great deal of emphasis.

Senator SCHMITT. So you would say, then, in the Fort Tejon area, where the Survey has taken a fairly definite position about the next 30 years, that it is still premature for the State of California to establish any criteria for new construction in that area?

Dr. SANDERSON. No, sir. I happen not to be the type of researcher who believes we've got to wait until the last answer is in before we make any decisions.

Senator SCHMITT. I was afraid, for a minute, that's what you were proposing.

Dr. SANDERSON. I think we need to make the best estimates that we can, on the basis of what we know now; and in many cases, those estimates are pretty good.

Senator SCHMITT. Do you know if the State of California is reacting in that way, to the Fort Tejon situation?

Dr. SANDERSON. That is not an area in which I am personally an expert. Some of the other people have maybe.

Senator SCHMITT. Our FEMA people are still here. Could I ask them if they know if the State of California is reacting, in their construction criteria, to the Fort Tejon predictions that the USGS has made?

Dr. THIEL. The State of California, under the Riley Act, requires all jurisdictions to meet certain minimum building code requirements. That is continuing to be enforced, and enforced vigorously.

Senator SCHMITT. Would you say that's adequate for the Fort Tejon area?

Dr. THIEL. For the Fort Tejon area, for selected types of structures? No, I wouldn't. There are steps being taken by the office of the State architect to change some of those design criteria and the reinforcement procedures that are applied.

Senator SCHMITT. Specific to that area? Or statewide?

Dr. THIEL. Statewide, in the high-risk areas and vicinities. It's not only around the Fort Tejon area, but also on the peninsula, in northern California.

Senator SCHMITT. What I'm getting at is: Here we have a survey with specific criteria. They have established, to their satisfaction, that we have a 50-percent probability of a magnitude-what? earthquake?

Dr. WESSON. Magnitude eight.

Senator SCHMITT. [continuing]. Or greater in the Fort Tejon area. Do you think it would be prudent for Federal buildings in that area, and State buildings in that area, that are going to be constructed within that 30-year period—assuming the earthquake occurs 30 years from now—to meet more strict criteria than you might require elsewhere?

I'm also thinking of the capital requirements that are necessary to build. You might consider focusing your effort on that area, rather than statewide.

Dr. THIEL. The response that I made had to do with the regulation of private construction, as opposed to public construction—Federal, State, county, or municipal. Publicly owned structures are not subject to any code in the State of California, unless they're schoolhouses or hospitals. There are discussions taking place under the Governor's Emergency Task Force On Earthquakes, of which I'm the Federal member, addressing that question, as well as a number of others. The Governor has become quite concerned, about preparedness in southern California, as has the State legislature, and passed legislation to provide funds for the support of preparedness efforts.

Thus the questions which are being asked, have not been definitively answered.

With respect to the question of whether there should be incremental design procedures now, the basic position of the professions is they have already factored in the risk in southern California to provide structures which have suitable life safety. That is, to protect life; not to protect property. The tradition of building codes is that it is a restriction on private property rights, to protect the life and safety of casual occupants; not to protect that property itself.

There is a substantial effort that Mr. Crawford referred to in his testimony, by the Building Seismic Safety Council, using the maps developed by the U.S. Geological Survey and the first tentative procedures developed under the support of the National Science Foundation, to change the design procedures used not only in southern California, but throughout the Nation.

This is a major effort to improve codes and standards.

Senator SCHMITT. Tell me, in light of the more legal argument you made about protecting casual occupants but not property—is this property eligible, under certain circumstances, for disaster reimbursement by the Federal Government or State government?

Dr. THIEL. Public property, yes. That represents a major problem.

Senator SCHMITT. What about private property?

Dr. THIEL. Generally not for grants to replace, but for low-interest loans and family grants.

Senator SCHMITT. Then there is a cost to the government if the property does not properly withstand an earthquake?

Dr. THIEL. That is correct. A very massive potential liability, measured in terms of tens of billions of dollars.

I might say that the Federal Government is acting to try to put its house in order for its own construction standards and practices. Under the Interagency Committee on Seismic Safety in Construction, we now have a proposed set of consistent earthquake-resistent design procedures in draft.

Senator SCHMITT. Mr. Sanderson, are you directly involved with FEMA in the evaluation of those standards?

Dr. SANDERSON. I am personally not directly involved.

Senator SCHMITT. Is the NSF?

Dr. SANDERSON. The NSF is involved to some extent in the evaluation of those standards.

Dr. THIEL. If I may, Jack.

Dr. John Scalizi, is a member of the interagency committee and in fact a leader of their design program, is a subcommittee representative, and has been responsible for the steel design procedures within these practices. The original documents from which we are working were, in many ways, developed from research and from applications activities of the National Science Foundation.

Senator SCHMITT. How long has this effort been ongoing?

Dr. THIEL. The interagency committee started in 1979. The effort to change seismic design codes in the United States started under a joint initiative among the professions, between the National Science Foundation, the Bureau of Standards, and then the Office of Emergency Preparedness, in 1973.

Senator SCHMITT. Thank you.

Dr. Brett, you heard the Survey folks mention what the three areas of research accomplishments they thought were particularly significant in the last 3 years were.

Would you care to add any to that list?

Dr. BRETT. Yes; I think I'd like to add some, and then pass it on to Leonard Johnson.

I think the whole area of gaps, which certainly was on their list, has opened up and we are certainly supporting research in this area. The whole topic of slow earthquakes is another exciting new area of research. Both of these are discussed in my written testimony.

Slow earthquakes are ground motions which are very slow, and may occur before a major quake; it is very difficult to use existing or regular seismometers to measure these things. They may have quite strong predictive capability.

Senator SCHMITT. Is this the gravity research that's underway? Is it related to that?

Dr. JOHNSON. Not exactly, it is just that these motions can be picked up on long period instruments, which also record changes in gravity.

So, in that sense, they're related.

There is separate gravity research going on. In particular, in China. We have a project in China where measurement of gravity is being used directly to try to discern some kind of premonitory effect.

Senator SCHMITT. But in a prototype system, you might well combine those two efforts into one?

Dr. JOHNSON. That is correct.

Dr. BRETT. The whole area of premonitory clustering has advanced considerably over the last 2 or 3 years. You may have heard of donut clusters for example.

We're in a position now—as again appears in the testimony—to understand, at least after the first 30 seconds, what appears on a seismogram, and in fact to numerically simulate these seismograms.

In other words, we are beginning to understand the process of what is causing each item on the seismogram.

I think right now I'm beyond my depth. But Dr. Johnson will be happy to go deeper if you have further questions there.

A very simple but important new area, that of determining frequency of earthquakes by carbon 14 dating and trenching is discussed in Dr. Wesson's testimony. This is largely performed by USGS contracts although NSF has supported it in the past. I think it will be an important new area of study, and it is relatively simple to do.

Finally, the COCORP project consisting of a consortium of universities, and run by Cornell uses a seismic reflection technique—an oil company technique by which we're understanding the continental crust, which is a major thrust of the earth sciences division. We can actually, through this seismic reflection study, get an understanding of the deep structure of a fault zone, right down through the crust.

And I think that COCORP investigations in some of the major fault zones will continue. So far, the Wind River thrust in Wyoming has been looked at, and a little bit of work has been done around the San Andreas Fault. It would certainly be interesting to get COCORP into the Wasatch Fault Zone.

I understand that USGA has done similar work around New Madrid. They're the areas that I think that have certainly paid off. There are other areas where there could be future work.

Dr. Johnson may wish to add to that.

Senator SCHMITT. Doctor, is that a sufficient summary?

Dr. JOHNSON. I think he stole most of my thunder. Yes.

Senator SCHMITT. He's very modest.

Dr. JOHNSON. I would like to say—to just put in a plug for the theoretical aspect of this whole thing—that it has really been the advent of large digital computers, along with the digital network instruments that now exist on a global basis—that has enable us to make significant advancements in our understanding of the earthquake source mechanism itself.

I think we've discovered that earthquakes are not as simple as we once thought they were. They can be, especially the large ones, very complicated multiple events, and we're beginning to get a handle on that now, with the new worldwide instruments, and some sophisticated advancements in theory.

Dr. SANDERSON. Senator Schmitt, there's a number of significant advancements and I've alluded to one or two of them earlier.

A very important advancement, from the point of view of the earthquake engineering program, has been the development and availability of large-scale experimental facilities. I mentioned earlier, we have provided considerable resources for the installation of strong ground motion accelerometers, so that we are now beginning to amass a sizeable collection of data on the true complexity of the strong ground forces that occur during an earthquake.

Another even more striking experimental facility is the one facility built by the Japanese at Tsukuba, the so-called science city, just outside Tokyo. They have constructed there a reaction wall testing facility, enabling us to test a full-scale seven-story building, essentially to destruction, using the pseudo-dynamic technique. The ability to test full-scale construction of this type is quite unique. We need this because the scaling laws are not well understood for vibration and deformation in buildings. We have a joint agreement negotiated between the National Science Foundation and the Ministry of Construction in Japan. Currently, the first full-scale test is being run on a reinforced concrete building. We hope to have an extension of the agreement signed in May, which will continue with the testing of steel frame buildings.

This has truly been a joint effort in which the Japanese and United States are splitting the cost of the actual experiments. The Japanese are providing the facilities and we are providing much of the experimental know-how and analytical work. This whole endeavor is a unique opportunity for fruitful international collaboration.

Another interesting project which we funded jointly with a number of organizations in California is a small but significant real contribution to knowledge. This is a look at some of the problems involving the liability that would occur to anyone who predicted an earthquake. As a result of this study, it was found that the liability under the laws of the State of California, for yelling "earthquake," were not clear; and that a person making such a prediction might be liable to considerable personal loss, if the prediction proved wrong.

As a result new legislation was introduced in the California legislature, to clear up the liability laws of the State so that as the ability to predict earthquakes comes onstream, it will not be at added personal risk to the person who is forced to make such a prediction.

Senator SCHMITT. Was that legislation passed?

Dr. SANDERSON. It's my understanding the legislation was passed. Yes, sir.

Senator SCHMITT. Is the administration considering any recommendations for Federal legislation along those lines?

Dr. SANDERSON. I'm not aware of any, Senator. Liability law of this type is generally handled in the State courts.

Senator SCHMITT. I recognize that. But some of the people making predictions might be Federal employees.

Dr. SANDERSON. Some of the people making predictions might be in this room, Senator.

Senator SCHMITT. Do you agree with the USGS witnesses, that we should begin to consider the next level of experiments, a prototype prediction system, rather than the pieces that we have been dealing with to date?

Dr. SANDERSON. In the prediction area, there's certainly enough indication that we understand sufficient pieces to begin pulling them together into a prototype system addressed specifically to the prediction area. In some of the engineering areas, there's still the need for a lot more fundamental research of the type that we're carrying on in the hazards mitigation program. In supporting that, I feel there's still the need for a great deal more basic research into the fundamental physical phenomena. All the signs are that enough indicators have been found, so that it's time to begin to organize a program to pull them together in a prediction experiment.

Senator SCHMITT. Dr. Brett, any comment on that?

Dr. BRETT. I agree, sir.

I think that more money could easily be spent in the basic research involved in understanding the earthquake process and plate tectonics, just as much as more research money needs to be spent in many other areas of the earth sciences.

Senator SCHMITT. Are we ready to move to the next major experiment, which is a significant-scale, site-specific predicting system?

Dr. BRETT. I'd defer on that question.

I think the answer to that question should be left to my colleague, Dr. Sanderson, and also to the U.S. Geological Survey, because our business, in the Earth Sciences Division, is to support basic research related to earthquakes in areas which the principal investigators or people doing the research think are good ones.

But I'm sure the thrust to study specific regions should be from the prediction and pragmatic sides of the program. Not that the pure research isn't ultimately practical and pragmatic, but I think the thrust should come from those areas.

I think you would find a number of basic researchers who would be happy to join in on such an organized project, and do their basic research in an area which was becoming increasingly better understood.

Senator SCHMITT. Does the area of ground squirrels and gophers fall into the National Science Foundation's area of research?

Dr. BRETT. The area of ground swirls?

Senator SCHMITT. Gophers and ants and other biological reactions to the changing motions as precursors to earthquakes?

Dr. BRETT. I thought you said swirls, and I didn't understand your accent, sir.

We, I understand, had a proposal some years ago before my time. If it is basic research, we haven't had many proposals in the last 2½ years. I don't know; do you receive proposals along those lines?

Dr. SANDERSON. No.

Senator SCHMITT. Do our Survey people that are still here know of any ongoing U.S. research on the use of biological precursors to earthquakes?

Dr. FILSON. Yes, sir. We have experiments with the Stanford Research Institute, which essentially performs a telephone answering service for people observing unusual activities in their pets or animals and call up and register such an observation with SRI, and statistical studies are being done to see if they can find any correlation between an increased number of reports prior to increased seismic activity. My understanding is, to date, no such correlation has been found.

Dr. SANDERSON. Senator Schmitt, I do have to correct myself. I have had two or three pieces of correspondence and telephone calls from an individual who asserted that she got migraine headaches just before an earthquake occurred, essentially along a latitudinal or longitudinal line that was fairly close to her location. She requested that the Foundation provide her with a WATS line so she could call us with the hazard warnings. I did not have the resources to provide her with a WATS line. However, I offered to accept a call if she would call me back but I haven't heard from her yet.

Senator SCHMITT. Do you think there is any biological precursor to be looked at?

Dr. SANDERSON. I don't know, sir.

Senator SCHMITT. Haven't the Chinese used this as part of their predictive system?

Dr. SANDERSON. The Chinese have cited this as part of their predictive capability.

Senator SCHMITT. Have we discussed this with them?

Dr. SANDERSON. Perhaps I should defer to the USGS.

Senator SCHMITT. I'm trying to find out whether this is applied research or basic research.

Dr. SANDERSON. Basically, the distinction that perhaps we didn't make clear enough is that the basic research in the Earth sciences is being carried out primarily by the National Science Foundation's Earth sciences program, represented here by Dr. Brett.

The problems of strong ground motion as related to designing structures that can withstand those strong ground motions are primarily the responsibility of the earthquake hazards mitigation program for which I'm responsible. The problems of understanding the precursors and the predictors for an earthquake are the responsibility of the USGS. That's the way the work in general has been divided.

Senator SCHMITT. Are there any botanists in the USGS and zoologists that are looking into these types of problems?

Dr. WESSON. Mr. Chairman, we have some paleobotanists, but they're not working on these problems. We have in the past, in addition to the work Dr. Filson alluded to at SRI, supported work by researchers in the academic community focused on this problem. Maybe better than saying basic and applied, we might refer to the Survey's program as a focused program, and at least the Earth science program as relatively unfocused. But in this focused effort at earthquake prediction, we've supported work by, for example, a researcher who was then at UCLA, who instrumented some burrows on ground squirrels in the Mojave Desert. The ground squirrels lived in multilevel burrows. Of course normally the ground squirrels during the day were on the bottom level of the burrow and then at night—they were nocturnal animals, so they would come up and be increasingly active at the higher levels. So he instrumented different levels of these burrows and watched the normal pattern of activity of the ground squirrels.

During the period of his experiment, he did see some interesting things which no one, at least as I know, understands yet. There was a period when the ground squirrels spent a lot of time in the upper levels of their burrow during the day. This preceded a small earthquake in the Mojave Desert. Unfortunately, we don't believe we can draw any conclusion from this yet. It's a somewhat better level of instrumentation than the anecdotal reports of the people in China, but still at this time it's largely anecdotal.

Just because we don't understand how homing pigeons fly home, it very well may be that animals—they can perform some kind of analysis or synthesis that we can't perform. So while we accorded this effort a rather low priority in our program so far, we haven't given it up.

Senator SCHMITT. There are variations in electric fields, are there not, preceding earthquakes? Haven't these been demonstrated?

Dr. WESSON. There are some indications of changes in resistivity.

Senator SCHMITT. Conductivity?

Dr. WESSON. Conductivity and resistivity. There are some ideas about changes in the electric field. There's a phenomenon called earthquake lights, of which pictures have been taken. It's kind of almost like the glow of the aurora borealis, either before or during earthquakes. No one yet understands this phenomenon. The animals might, in fact, be responding to something like that.

Senator SCHMITT. Just very imperceptible ground swells?

Dr. WESSON. Mr. Chairman, that's a very interesting point. Commonly dogs will bark right before an earthquake or something like that, or cats will do something strange. It turns out that the p-waves of an earthquake can be coupled into the atmosphere, so if you're standing on the ground and there's an earthquake somewhere underneath, usually what you feel are the p-waves. I'm sorry—usually what you feel are the s-waves or the surface waves shaking you, but the p-waves couple to the atmosphere, so sometimes you will hear a noise before you feel the shaking, and in some cases these noises might be of very low amplitude, and so the animals could hear them. So it doesn't surprise anyone that animals might act strangely a few seconds before an earthquake is felt. I think we can understand that.

It's the longer term, maybe electrical or whatever kind of phenomenon that precede an earthquake by hours or many minutes that's up in the air.

Senator **Schmitt**. Thank you. Thank you, gentlemen. We may have a few more questions for the record.

We will try to and I expect will have a reauthorization out shortly. As I've indicated earlier, it may be the committee's decision to reauthorize for only a year, not because of any lack of interest in the program but because we think we need more time to work with the new administration on developing what may be a broader based program and what it might be.

Thank you very much. The hearing is adjourned.

[Whereupon, at 3:05 p.m., the hearing was adjourned.]

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